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Diversity of *Bactrocera* spp. in Different Habitat Types in Citrus Orchards at Malang Regency

Yunita Fera Rahmawati[1,2*], Amin Setyo Leksono[1], Zulfaidah Penata Gama[1], Akhmad Rizali[3]

[1]Department of Biology, Universitas Brawijaya, Indonesia
[2]Department of Biology Education, Universitas Negeri Yogyakarta, Indonesia
[3]Department of Plant Pests and Diseases, Universitas Brawijaya, Indonesia

Abstract

Fruit flies are significant pests of citrus crops. Identifying their species is crucial for drawing appropriate conclusions and determining effective control methods. Hence, this study aimed to identify the dominant species, calculate the diversity index, and document fruit fly species in Siam citrus (*Citrus nobilis* Lour.) orchards in Dau District, Malang Regency, Indonesia. The research was conducted in two habitat types: areas near and far from residential zones. Six petrogenol-treated traps were placed at each location from December 2022 to February 2023, and fruit flies captured in the traps were counted biweekly as part of the survey. The results identified three species, including *B. dorsalis*, *B. carambolae*, and *B. umbrosa*, in locations close to residential areas, whereas *B. umbrosa* was absent in locations far from residential areas. *B. dorsalis* was the dominant species in both locations. The diversity index of *Bactrocera* spp. in orchards near residential areas was 1.14 (moderate), and Spearman's correlation analysis (0.913) indicated a stronger influence compared to orchards far from residential areas. Climatic factors such as humidity, air pressure, and host availability were essential determinants of fruit fly presence.

Keywords: *Bactrocera* spp., citrus, diversity, residential areas, traps

Introduction

Siam citrus (*Citrus nobilis* Lour.) is one of Indonesia's most commercially important fruit crops. Indonesia's citrus cultivation spans over 57,000 hectares, producing 2.5 million tons annually. However, the production in 2021 decreased by 7.67% compared to 2020 (BPS, 2023). One major factor contributing to this low productivity is pest and disease attacks, which can lead to yield losses ranging from 50% to 90%. As a result, farmers heavily rely on pesticides for control. Among the various insects attacking citrus plants, fruit flies are primary pests, significantly reducing the quality and production.

Fruit flies in citrus cultivation remain a major export constraint (Enkerlin, 2021). Species such as *Bactrocera cucurbitae*, *B. dorsalis*, *B. zonata*, *B. tau*, *B. scutellaris*, *B. yashimotol*, *B. minax*, *B. caudatus*, *B. correcta*, and *B. diversus* are the most commonly found in horticultural ecosystems, attacking a variety of fruits (Saeed et al., 2022). Fruit fly infestations reduce the competitiveness of citrus in the international market and restrict export activities. According to Singh (2020), fruit flies of the genus Bactrocera exhibit excellent flight capabilities, traveling up to 2 kilometers in search of food. Depending on the range, location, and season, these pests cause 40-80% crop damage (Kibira, 2015). Quarantine

*Corresponding Author: Yunita Fera Rahmawati, email: yunitafera@student.ub.ac.id; yunita.fr@uny.ac.id; Universitas Brawijaya. Jl. Veteran No.10-11, Ketawanggede, Kec. Lowokwaru, Kota Malang, Jawa Timur 65145

restrictions imposed by importing countries further limit access to international markets (Chalam et al., 2021). The European Union (EU), for instance, enforces stringent quarantine measures for fresh commodities. Detection of a single larva in a mango shipment at the point of entry can result in the destruction of the entire shipment (Ansari et al., 2019). Moreover, such incidents may lead to export bans for the country of origin.

Fruit flies cause substantial damage by piercing fruits to lay eggs, allowing larvae to develop within (Theron et al., 2023). Female fruit flies lay eggs inside fruits, damaging nearly 400 varieties of fruits and vegetables, including key crops such as apples, guavas, mangoes, papayas, melons, and passion fruits. These pests are highly destructive and are considered polyphagous due to their wide range of host plants, high fecundity, and ability to spread rapidly across large areas. This makes them detrimental to fruit and vegetable growers (Boulahia-Kheder, 2021). A survey conducted in South China revealed that the fourth generation of *B. dorsalis* caused the most significant damage in citrus orchards, influenced by host availability and winter temperature conditions (Li et al., 2024).

Fruit flies depend on various plant parts to meet their essential needs, including sustenance, reproduction, and shelter. Orchard composition strongly influences their diversity, especially in areas dominated by specific fruit-bearing plants. The availability of suitable host plants is a critical factor in determining the prevalence of pest species. Understanding fruit fly biodiversity in conservation areas offers valuable insights for developing effective management strategies and enhancing knowledge of potential pest fauna affecting fruit trees.

This research on the diversity of *Bactrocera* spp. across different habitats provides new perspectives on agricultural landscapes. It also sheds light on the potential of residential areas as natural reservoirs for fruit fly populations, which may affect pest population dynamics in commercial citrus-growing areas.

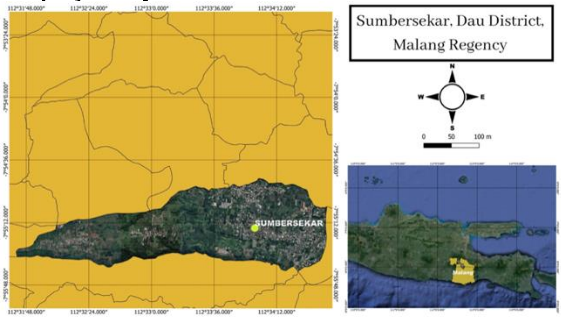
The present study examined the diversity and species composition of fruit flies on citrus trees in the Dau District and its surroundings. Information on the abundance of fruit fly species in citrus orchards in Sumbersekar Village, Dau District, was unavailable. In addition, this study attempted to identify the diversity of fruit flies in two locations, namely orchards near residential areas and those farther away, as well as to determine climatic factors influencing the presence of fruit flies.

Research Method

This research was conducted from December 2022 to February 2023 in two orchards in Banjartengah Village, Sumbersekar, Dau District, Malang Regency, Indonesia (see Figure 1). The study sites consisted of two locations: one orchard near residential areas (Location I: S07°55.123' E112°34.044') and another far from residential areas (Location II: S07°55.134' E112°34.160').

Figure 1

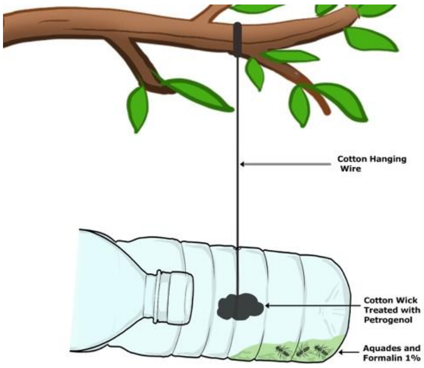
Map of study sites.



Trapping

The traps were made from 1,500 ml mineral water bottles. At the top of each bottle, ± 7 cm holes were made around the body in three zig-zag rows, with each hole having a diameter of ± 0.7 cm to allow fruit flies to enter. A wire ± 50 cm long was inserted through the bottle cap to hang cotton soaked in methyl eugenol (ME) (trademark: Petrogenol) and to suspend the traps from citrus trees. A cotton roll with a diameter of ± 1 cm, soaked in ME, was used to ensure the aroma could spread and attract fruit flies. The cotton roll was attached to the end of a 2.10 mm diameter wire inside the bottle. Before installation, the prepared trap bottles were filled with 200 ml of water mixed with 1% formalin. The trapping model was adapted from Rahmawati et al. (2024) and is illustrated in Figure 2. Male fruit fly attractants, such as cue lure and methyl eugenol, are critical for monitoring and managing fruit fly pest species. Furthermore, the use of attractants is essential for the effective management of pest through male reduction techniques and the detection of invasive pest populations using traps (Duan et al., 2024).

Figure 2
Fruit fly bottle trap.



Observation of Fruit Flies

Monitoring was conducted in citrus orchards in Banjartengah, Sumbersekar, Dau District, Malang Regency across two habitats: one near residential areas and another farther away. The citrus orchards near residential areas spanned 1,300 square meters, with a planting distance of 5 m x 5 m, containing 135 trees. In contrast, the orchard farther from residential areas covered 1,100 square meters, with a spacing of 1 m x 1 m, and contained 112 trees. Fruit fly traps were set up by suspending wires 10 meters from tree branches at 1.5 to 2 meters above the ground. A total of six traps were placed at the edges of the orchard. Observations and trap replacements were conducted biweekly over eight weeks. Each trap was baited with 0.5 to 1 cc of attractants applied to a cotton ball.

Trapped fruit flies were collected in brown paper bags and later identified at the Animal Ecology and Diversity Laboratory, Department of Biology, Universitas Brawijaya. Identification was performed morphologically using a trinocular stereo microscope equipped with a Nikon DS-Fi3 camera. The number of trapped male and female fruit flies was recorded based on morphological characteristics. Identification followed the key book for tropical fruit flies in Northwest Australia, Indomalaya, and Southeast Asia (Drew & Romig, 2013). Climatic factors, including temperature, humidity, light intensity, and wind speed, were also recorded to determine their influence on fruit fly population diversity.

Data Analysis

Data on fruit fly species, abundance, and climatic factors were analyzed using the Shannon-Wiener diversity index. The formula for the Shannon-Wiener diversity index was based on Konopiński (2020):

$$H' = - \sum (ni/N.\ In\ ni/N)$$

Notes:
H': Shannon-Wiener species diversity index
i: Abundance of species *i*
N: Total abundance of all species observed

Spearman rank correlation analysis was employed to assess the correlation between the two research locations and the capture rates of fruit fly pests.

Research Results and Discussion

The identification results showed that three species of fruit flies were found in citrus orchards in Sumbersekar Village, Dau District, Malang Regency: *Bactrocera dorsalis*, *Bactrocera carambolae*, and *Bactrocera umbrosa*. *B. carambolae* and *B. dorsalis* are closely related species (Zimowska et al., 2024). Another fruit fly species, *B*. *umbrosa*, was found only in orchards near residential areas. This species is the primary pest of a limited number of *Artocarpus* species. It is an oligophagous pest that targets fruits of the *Moraceae* family. This species is distributed across Southeast Asia and the Western Pacific (Hidayat et al., 2023; Kim et al., 2021). Previous studies in Indonesia have also reported its presence in citrus orchards (Hidrayani et al., 2024; Soraya, 2019).

The characteristics of fruit flies are determined by their morphological features, particularly in the head, thorax, and abdomen. On the head, the observed characteristics included antennae, compound eyes, and the presence or absence of black spots or straight-line patterns (Galinskaya et al., 2020). Both *B. umbrosa* and *B. dorsalis* share similar head characteristics, such as oval-shaped facial spots, aristate antennae, six circular points, hair-like structures, and a pair of black compound eyes (Akbar et al., 2020). However, a distinguishing feature is the color of the lunula: *B. dorsalis* has a yellow lunula, while *B. umbrosa* has a yellowish-brown lunula. Additionally, the facial color of *B. dorsalis* is predominantly yellow with brown stripes, whereas *B. umbrosa* has a dominant brown facial color (Riastiwi et al., 2021).

The thoracic characteristics of these three fruit fly species also exhibit significant differences. *B. dorsalis* has a black dorsal thoracic pattern, while *B. umbrosa* has a brick-red dorsal thoracic pattern with black stripes (Tan et al., 2021). Furthermore, *B. dorsalis* features a scutum with a black base color surrounded by bristles, a pale-yellow scutellum with black spots, and two setae (Abdellah et al., 2020). In contrast, *B. umbrosa* has a brick-red scutellum base with yellow scutellum coloring and two setae, but both species lack medial-lateral vittae (Manurung et al., 2020). Another distinguishing feature lies in the lateral post-sutural vittae: *B. dorsalis* has pale yellow, almost white parallel vittae, whereas *B. umbrosa* exhibits widened, bright yellow post-sutural lateral vittae (Daud et al., 2020) (see Figures 3-5).

On the thorax, a distinguishing feature of these three types of fruit flies is the characteristics of their wings. These include the wing pattern and the coloration of the costa band, anal streaks, and microtrichia. The wing pattern of *B. umbrosa* fruit flies consists of three distinct patterns in addition to the costa and cubital streak patterns (Susanto et al., 2022). In contrast, the wing patterns of *B. dorsalis* flies lack additional patterns beyond the costa and cubital streaks. The costa stripe and anal stripe of *B. dorsalis* are blackish-brown, while those of *B. umbrosa* are brown (Sulaeha et al., 2020). The microtrichia near the anal line are visible in *B. dorsalis*, but they are less distinct in *B. umbrosa*. Observations suggested that the critical characteristics of fruit flies can be identified through their wing features, including the pattern, costa length, cubital stroke, anal stroke, wing colors, and other structures (Manurung et al., 2022). The banding pattern extends beyond the tips of R2+3 and R4+5 to the apex. However, in *B. carambolae*, the black pattern overlaps at R2+3, extends past the tips of R2+3 and R4+5, and displays a widened band at the apex (Mondal et al., 2020) (see Figures 3-5).

Another distinguishing characteristic of the thorax is the legs. Variations in the tibia and femur coloration and the presence or absence of black spots on these structures are key in identifying different types of fruit flies Black spots on the femur or tibia are often crucial for distinguishing species (Abdellah et al., 2020). Both *B. dorsalis* and *B. umbrosa* fruit flies have yellow-colored femurs and tarsi, but their tibiae differ in coloration. *B. dorsalis* has black tibiae, while the tibiae of *B. umbrosa* are yellow (Sulaeha et al., 2020)(see Figures 3-5).

The abdomen is another body part used to differentiate between fruit fly species. The abdomens of the three fruit flies are oval-shaped and brown (Putri et al., 2024). Differences in abdominal features include the presence or absence of a T-shaped pattern on the third to fifth terga, ceromata, dark brown coloration, and a black line on the third tergum (Sari et al., 2022). *B. dorsalis* fruit flies exhibit a visible T-shaped pattern on the third to fifth terga, with a thinner and narrower T-pattern on tergum IV. In contrast, *B. carambolae* has a square-shaped black pattern at the end of tergum IV (Susanto et al., 2022). Additionally, *B. dorsalis* has a black transverse line on the second tergum, and its ceromata are less visible. The abdomen of *B. umbrosa* has a dark brown pattern on the third tergum and brightly colored ceromata, which are dark brown on the fifth tergum (Herrahmawati et al., 2023). In both species, the pectus is located on the fourth tergum of the abdomen (Hasinu et al., 2020) (see Figures 3-5).

Figure 3a-e.
Bactrocera dorsalis (Hendel): **A)** Lateral view; **B)** Head; **C)** Head and scutum; **D)** Abdomen; **E)** Wing. (Scale: 1 mm).

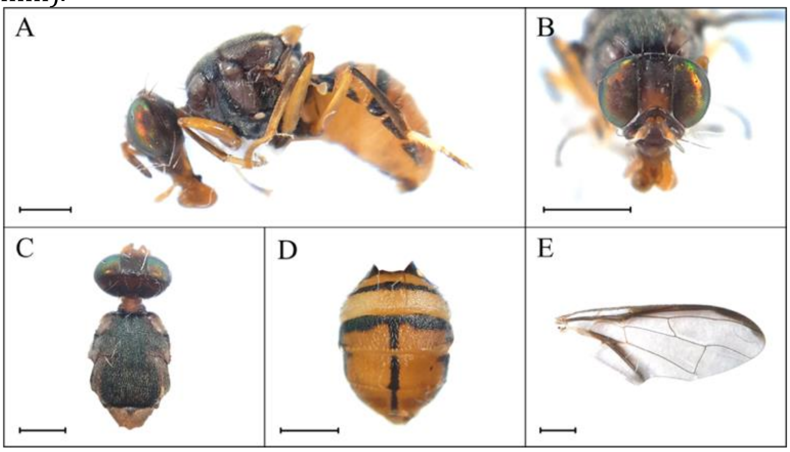


Figure 4a-e.
Bactrocera carambolae (Drew): **A)** Lateral view; **B)** Head; **C)** Head and scutum; **D)** Abdomen; **E)** Wing. (Scale: 1 mm).

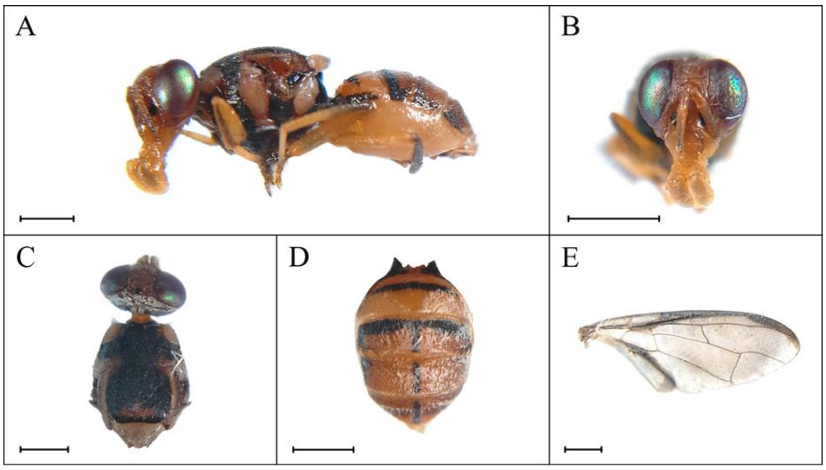
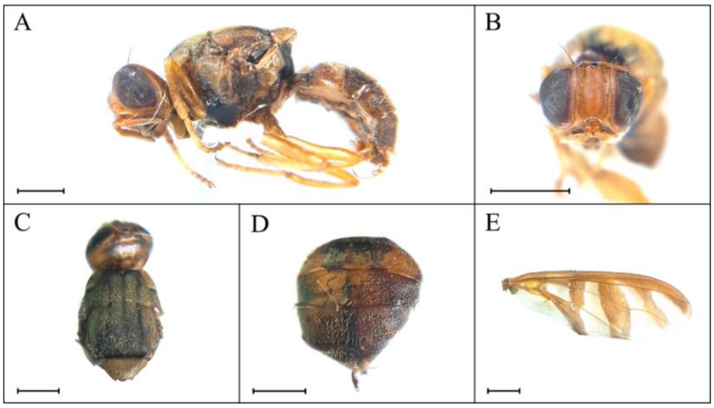


Figure 5a-e.

Bactrocera umbrosa (Fabricius): **A)** Lateral view; **B)** Head; **C)** Head and scutum; **D)** Abdomen; **E)** Wing. (Scale: 1 mm).



According to the data presented in Table 1, the prevalence of *B. dorsalis* species was observed among fruit flies at the specified site. Male fruit flies accounted for 58% of the total trapped specimens, while female fruit flies constituted 55% of the captured specimens. The *B. dorsalis* species has been found to cause significant harm to citrus, a crucial fruit crop (Mutamiswa et al., 2021). In both locations, the fruit flies exhibited a higher proportion of males than females.

Methyl eugenol (ME) is a chemical compound that acts as a male attractant, effectively suppressing and eradicating pest populations by reducing mating frequency (Momen et al., 2024). Males attracted to ME exhibit distinctive flight patterns, flying downwind in a zigzag manner toward the ME source, with some demonstrating remarkable flight capabilities in less than 10 seconds. Upon landing, each male extends its proboscis to consume the ME source. When multiple males are present, competitive behavior emerges, with dominant males attempting to restrict other males' access to the ME source (Kardinan & Maris, 2022).

The presence of insects in a habitat is influenced by several factors, including cultivation techniques, pesticide use, and habitat characteristics (Sánchez-Bayo, 2021). These habitats provide essential resources such as food, alternative hosts, and shelter (Iuliano & Gratton, 2020). According to the Shannon-Wiener diversity index (H'), fruit fly diversity was higher in locations near residential areas than those farther away (H' = 1.14). This finding was further supported by Spearman's rho correlation test, which revealed stronger correlations between *Bactrocera* spp. abundance in ME traps and orchards near residential areas (0.913) compared to those farther away (0.817).

The high abundance of fruit flies in areas close to residential populations is supported by several ecological factors, especially host availability and environmental conditions. The higher density of citrus trees in residential areas provides substantial food resources and oviposition sites for fruit flies, favoring larger populations (García-Olivos et al., 2024). This aligns with the resource concentration hypothesis, which suggests that herbivorous insects are more likely to find and remain in areas

Table 1*. Identification results of fruit fly species on citrus orchard*

Species	Field type	
	Near residential areas	**Far from residential areas**
B. dorsalis ♂	164	112
B. dorsalis ♀	33	6
B. carambolae ♂	158	32
B. carambolae ♀	20	4
B. umbrosa ♂	4	0
B. umbrosa ♀	0	0
H-Index	**1.14 (Moderate)**	**0.77 (Low)**

Table 2*. Results of citrus orchard climatic measurements*

Field type	Climatic factors			
	Temperature (°C)	**Humidity (%)**	**Light (Lux)**	**Wind (Knot)**
Near residential areas	33-34	66-68	3168-3438	0.04-0.06
Far from residential areas	32-34	66-68	3630-6750	0.45-0.73

with high concentrations of host plants (Silva & Clarke, 2020). Research has demonstrated that the consistent availability of host plants throughout the season significantly impacts fruit flies' population dynamics and their spatial distribution patterns (Salazar-Mendoza et al., 2021).

In addition, artificial lighting in residential areas creates a unique microenvironment that can influence fruit fly behavior. Nighttime lighting attracts various insect species, including fruit flies, and influences their movement patterns and habitat selection (Wilson et al., 2021). This attraction to artificial light at night is followed by movement into citrus groves to forage in the morning. This suggests a complex interaction between anthropogenic factors and insect behavior. This diurnal pattern aligns with studies showing that fruit flies exhibit peak activity in the morning and evening, possibly as an adaptation to optimize foraging efficiency and avoid heat stress during the day (Dukas, 2020). In the present study context, the combination of artificial lighting and abundant host plants contributed to a higher fruit fly presence in areas close to residential houses than those farther away.

As shown in Table 2, environmental factors significantly influenced the presence of insects in habitats. The study sites exhibited varying characteristics, with 135 citrus trees recorded in locations near residential areas compared to 112 trees in more distant locations. This difference in host plant density directly affected the availability of resources for fruit fly species. Furthermore, understory vegetation surveys revealed greater plant diversity near residential areas, with 21 species documented compared to 16 species in remote locations. Dominant understory species common to both locations included *Galinsoga parviflora*, *Ageratum conyzoides*, *Euphorbia hirta*, *Roppipa indica*, *Emilia sonchifolia*, and *Torenia crustacea*. These ground cover plants significantly contributed to the habitat's functional biodiversity, influencing insect populations at the study sites (Inagaki et al., 2022).

Other factors influencing the diversity of *Bactrocera* spp. included air temperature, humidity, light intensity, and wind speed (Zhang et al., 2022). During the research period, the average temperature in both locations was 33°C, which was not optimal for fruit fly development. This might explain why the diversity of *Bactrocera* spp. was categorized as moderate at the first location and low at the second. Fruit flies can survive and grow within a temperature range of 10-

30°C, with an optimum range of 20-28°C (Dongmo et al., 2021). Humidity measurements in both locations exhibited an average value of 66-68%, supporting the development of pupae and the survival of *Bactrocera* spp. However, at high humidity levels (80-90%), *Bactrocera* spp. pupae could not develop properly (Heve et al., 2021).

Light intensity also played a crucial role in determining the presence of *Bactrocera* spp. In both research locations, the average light intensity was 3,000 lux. This high light intensity posed a challenge, contributing to a decline in fruit fly populations during the third and fourth collection periods and reduced host availability in both locations. This species is most active in the morning, requiring dim light for copulation activities, typically within the 50-1,000 lux range for about one hour (Ren et al., 2023).

Wind speed was another climatic factor observed during the eight weeks of study. The average wind speed at both sites was 0.385 knots, likely due to the dense vegetation serving as a barrier between gardens. Low wind speeds influence the active movement of fruit flies. In a previous relevant study, the efficacy of fruit fly management in mango plantations could be optimized by deploying traps during reduced sunlight and low wind speeds. Additionally, trap placement could be adjusted based on fruit fly orientation (Susanto et al., 2022).

Conclusion

Insect diversity was found to be significantly higher in citrus orchards near residential areas compared to those in distant locations. This higher diversity was evidenced by the Shannon-Wiener diversity index (H' = 1.14) and supported by the strong correlation coefficient (Spearman's rho = 0.913) for trap effectiveness at the study sites. The diversity of *Bactrocera* species appeared to be influenced by food resource availability and environmental factors, particularly low air humidity and wind pressure. Three species, namely *B. dorsalis*, *B. carambolae*, and *B. umbrosa* were found in locations close to residential areas; meanwhile, *B. umbrosa* was absent in locations far from residential areas. The dominant species was *B. dorsalis* at both sites. These findings emphasized the significance of continuously surveilling alternative host plants and developing effective management strategies to minimize fruit damage and address quarantine concerns.

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