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Food Attractants and Trapping Methods for Monitoring *Drosophila suzukii* and *Zapronius indianus* (Drosophilidae) in Fig Orchards

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ABSTRACT

Drosophila suzukii Matsumura and *Zaprionus indianus* Gupta (Diptera: Drosophilidae) are invasive pests affecting fig crops in Mexico. Monitoring the density of fruit fly populations plays an important role in deciding pest management strategies. In fruit and vegetable production, food baits and traps are commonly used to monitor and control these pests. However, many local fig farmers have limited access to advanced technologies and are constantly seeking affordable and effective solutions to improve their crop yield and income. In this study, we tested three different trap designs (two commercially available and one handmade from plastic) and 3 food baits to capture adults of *D. suzukii* and *Z. indianus*. 2 trials were conducted in local fig orchards during different periods: November-December 2018 and July-August 2019. The handmade plastic traps, when baited with commercial attractants, performed similarly to the commercially produced traps for both fruit fly species in both trials. The paper also discusses the impact of the trap design on its effectiveness in attracting and capturing the fruit flies. The study region is known for its high population density of *D. suzukii* and *Z. indianus*.

Keywords: Handmade trap, Fig flies, Trapping, Drosophilid flies

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Introduction

The fig tree (*Ficus carica* L., Moraceae) originates from the southwestern Mediterranean region and is regarded as the first plant to be domesticated by humans [1]. This crop is grown across temperate, tropical, and subtropical zones, with its resilience allowing it to thrive in various soil types [2]. Globally, fig cultivation spans over 376,100 hectares, yielding around 1,064,400 tons, with Turkey being the leading producer [3]. In Mexico, the cultivated area was reported to be 1,357 hectares in 2018, with a production of 7,700 tons and a total economic value of eight million dollars [4]. The primary fig-producing regions are in central Morelos, which are characterized by a relatively low level of technological development [5]. Pest management in these areas mainly relies on the regular application of chemical pesticides.

Two species of Drosophilidae (Insecta: Diptera) have recently been impacting the quality and phytosanitary condition of fruits: *Drosophila suzukii* Matsumura and *Zaprionus indianus* Gupta [6, 7]. These species are known to be particularly harmful to fruits such as strawberries, peaches, blackberries, figs, and other small fruits with delicate outer skin [5, 8, 9].

D. suzukii, native to Southeast Asia [10] and first described in Japan in 1931 [11], was recognized as an invasive species in Mexico in 2011, initially limited to Los Reyes in Michoacán [12]. Currently, it is found throughout Mexico and falls under government regulation, although it only qualifies as a quarantine pest in areas with cultivated host plants [7, 13]. In contrast to other drosophilids, *D. suzukii* has a serrated ovipositor, which enables it to cut into the skin of fruits, allowing it to lay eggs in both mature and unripe fruits. This species primarily feeds on overripe or decaying fruit [14, 15].

Z. indianus was first identified in Brazil on fig fruits, where it caused significant damage, leading to losses of 40 to 50% in commercial fig crops. It was referred to as the African fig fly [16]. In Mexico, the species was first detected in Chiapas in 2002 [17], and although it has not been widely studied, it has spread across crops in 7 federal entities [6, 7, 17]. In fig cultivation, it is regarded as a major pest [18]. Unlike *D. suzukii*, *Z. indianus* lacks a serrated ovipositor and instead lays its eggs by entering the ostiole of figs as they approach maturity [19].

As part of integrated pest management strategies for these drosophilid species, traps are used to monitor adult populations in fig orchards and regions with potential for infestation [20]. These traps help determine the presence or absence of adult flies and track population trends. Local farmers commonly use handmade plastic jar traps baited with apple cider vinegar, placed 1 km apart in designated quadrants [5], in addition to the typical Multilure© traps used for other fruit fly species (personal observation). Various commercial and homemade baits, such as those based on apple cider vinegar, wine, and yeast, have been tested for fly monitoring purposes [21]. However, apple cider vinegar has been shown to attract a broad range of Drosophilidae species, including non-target species, as well as other flies (Diptera), moths (Lepidoptera), wasps (Hymenoptera), and beetles (Coleoptera) [22, 23].

There are commercially available traps (such as Multilure© and Pherocon SWD©) and food attractants (including Pherocom SWD© Dual-Lure and Suzukii Trap©) that are recommended for both monitoring and mass trapping of these and other fruit fly species. However, these products have not been tested in the specific conditions faced by local growers in Morelos. The objective of this study was to assess the effectiveness of commercial baits and traps in monitoring adult populations of two drosophilid species (Insecta: Diptera) that pose economic threats to fig crops in Morelos, Mexico.

Materials and Methods

Experiment location

The study took place in commercial orchards of Black Mission figs in Ayala, Morelos, Mexico (18.734206° -98.915858). This region experiences a warm subhumid climate, with an average annual temperature of 24 °C [24].

Traps and food baits

The study employed two commercially available traps, Multilure© (Ferommis, Mexico) and Pherocon SWD© (Trécé, Inc., United States), along with a DIY jar trap. These handmade traps were created using one-liter plastic jars, featuring 10 holes (4 mm each) placed around the upper edge of the jar, with a red-colored base [5, 25]. Three food baits were tested: Suzukii Trap© (Bioiberica, Spain), Pherocon SWD© Dual-Lure© (Ferommis, Mexico), and Cera Trap© (Agrotecnologia Alternativa, S.A. de C.V., Mexico). Each Suzukii Trap© and Cera Trap© received two hundred fifty ml of liquid bait, while for the Pherocon SWD© Dual-Lure, a dispenser was installed inside the trap. Soapy water (5%) was used in all traps for insect retention.

Experimental design

The study analyzed two factors: trap type (3 levels) and food bait (three levels), resulting in nine possible combinations of treatments. The treatments were: 1) Handmade plastic jar with Cera Trap©; 2) Handmade plastic jar with Suzukii Trap©; 3) Handmade plastic jar with Pherocon SWD© Dual-Lure©; 4) Multilure© with Suzukii Trap©; 5) Multilure© with Suzukii Trap© (duplicate); 6) Multilure© with Pherocon SWD© Dual-Lure©; 7) Pherocon© with Suzukii Trap©; 8) Pherocon© with Suzukii Trap© (duplicate); 9) Pherocon© with Pherocon SWD© Dual-Lure©.

A completely randomized block design was used, with each treatment replicated four times, arranged in four rows. Traps were inspected weekly, and treatments were randomized each week to prevent positional bias. The traps were spaced 20 m apart, with 30 m between rows, and placed at ¾ height of the trees, avoiding direct sunlight exposure. The experiment was conducted twice: the first from November 19 to December 24, 2018, and the second from July 12 to August 16, 2019. During both periods, the fruits were at ¾ of their physiological maturity. The Pherocon SWD® Dual-Lure© dispensers were replaced every 4 weeks, and soapy water was refreshed weekly. The Suzukii Trap® and Cera Trap® baits were replenished as needed.

Entomological determination

All collected specimens were stored in 70% alcohol and identified using taxonomic identification keys [26].

Data analysis

The normality and variance homogeneity of the data were evaluated by species, followed by the comparison of treatment means using ANOVA. When important differences were found, the Fischer test was applied ($\alpha = 0.05$). In the 2nd period, a data transformation ($\sqrt{X} + 0.5$) was applied to normalize the distribution and standardize the variation before performing the analysis.

Day trap flies index (DTF)

The Day Trap Flies index is utilized to assess the relative abundance of adult fruit flies in a specific area and period, a method commonly applied to native fruit flies in the Anastrepha genus (Diptera: Tephritidae). It helps in selecting appropriate management strategies for tephritid populations [27]. The index was calculated for each species per treatment [5].

$$DTF = F/(TxD) \quad (1)$$

Donde:

F= Number of flies collected

T = Total number of traps revised

D = Number of days those traps were exposed in the field

DTF is expressed in the format 0.0000 [28], and level prevalence is categorized as high (≥ 0.0100), low (≤ 0.0100), and absent (0.0000).

Results and Discussion

Monitoring plays a crucial role in identifying the presence or absence of pests in crops, enabling informed decisions for their effective management [21]. For fruit flies, both the trap design and the choice of food bait significantly impact the capture of adult flies [29, 30]. The trap should be designed to attract fruit flies, capable of holding the food bait over time and releasing its compounds. Simultaneously, the food bait must be an effective attractant and serve as a means of retaining the flies [31].

First trial

Traps and food baits

A total of 4,458 specimens were captured, with 8.0% (373) identified as *D. suzukii* and 92% (4,285) as *Z. indianus*. The type of bait used had an impact on which species of drosophilids were caught. Suzukii Trap© proved more effective for capturing *D. suzukii*, but only when paired with handmade or Multilure® traps. Its attraction to *D. suzukii* was lessened when used in conjunction with the Pherocom© trap **(Figure 1a)**. This bait also attracted other non-target Drosophilidae (data not displayed). In contrast, when the Pherocom SWD© Dual-Lure© was used with the Pherocom© trap, the capture rates were similar to those of Suzukii Trap© with handmade or Multilure® traps.

For *Z. indianus*, handmade plastic traps baited with Pherocom SWD© proved to be the most successful, collecting three to five times as many specimens compared to other treatments **(Figure 1b)**.

Cera Trap®, regardless of the type of trap used, failed to capture any specimens of either species **(Figures 1a and 1b)**.

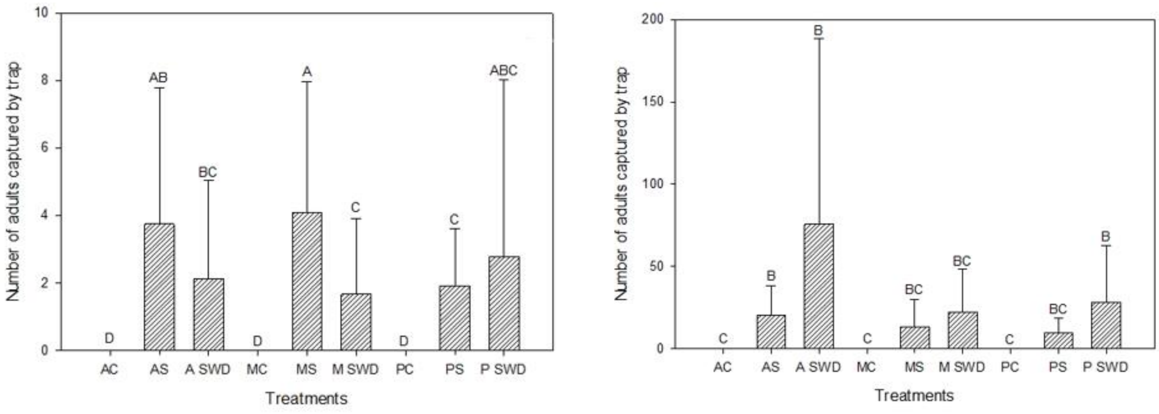


Figure 1. *D. suzukii* (a) and *Z. indianus* (b) were captured in a combination of three traps and food baits in Ficus, Mexico (November-December 2018); AC: Handmade trap + Cera Trap©, AS: Handmade trap+ Suzukii© trap, ASWD: Handmade trap + Pherocom SWD© Dual-Lure©, MC: Multilure© trap + Cera Trap©, MS: Multilure© trap + Suzukii© trap, MSWD: Multilure© trap + Pherocom SWD© Dual-Lure©, PC: Pherocom© trap + Cera Trap©, PS: Pherocom© trap + Suzukii© trap, and PSWD: Pherocom© trap + Pherocom SWD© Dual-Lure©.

DTF index

The combination of traps and food baits influenced the population prevalence of *D. suzukii*, as reflected by the DTF index. The highest index was observed when Multilure© traps were paired with Suzukii Trap© as the bait, with similar results seen when Suzukii Trap© was used with handmade plastic jar traps. When Pherocom© traps were used with Pherocom SWD© Dual-Lure© bait, the DTF index was comparable to the combination of Multilure© and Suzukii Trap© **(Table 1)**. Other treatments showed less impact on the DTF index, and traps baited with Cera Trap© didn't yield any measurable results. The use of Suzukii Trap© and Pherocom SWD© Dual-Lure© baits in all traps led to a high population prevalence of *D. suzukii*.

Table 1. *D. suzukii* population prevalence index (day trap flies (DTF)), including the highest and lowest values calculated using various traps and food baits in figs from Morelos, Mexico (November-December 2018).

Treatment (trap plus food bait)	Maximum prevalence level	Minimum prevalence level	Weeks with prevalence values of 0.0000
Handmade + Cera trap©	0.0000	0.0000	6
Handmade + Suzukii trap©	0.9200	0.2500	0
Handmade + Pherocom SWD© Dual-Lure©	0.8500	0.0700	0
Multilure© + Cera trap©	0.0000	0.0000	6
Multilure© + Suzukii trap©	1.1700	0.3200	0
Multilure© + Pherocom SWD© Dual-Lure©	0.5700	0.0300	0
Pherocom© + Cera trap©	0.0000	0.0000	6
Pherocom© + Suzukii trap©	0.4600	0.1700	0
Pherocom© + Pherocom SWD© Dual-Lure©	1.0000	0.0700	0

Table 2. Population prevalence index of Day Trap Flies (DTF), showing the maximum and minimum values for *Z. indianus* with various traps and food baits in figs from Morelos, Mexico (November-December 2018).

Treatment (trap plus food bait)	Maximum prevalence level	Minimum prevalence level	Weeks with prevalence values of 0.0000
Handmade + Cera trap©	0.0000	0.0000	6
Handmade + Suzukii trap©	8.8500	1.0700	0
Handmade + Pherocom SWD© Dual-Lure©	33.4000	2.2800	0
Multilure© + Cera trap©	0.0000	0.0000	6
Multilure© + Suzukii trap©	2.8900	0.1740	0

Multilure© + Pherocom SWD© Dual-Lure©	7.4200	1.2800	0
Pherocom© + Cera trap©	0.0000	0.0000	6
Pherocom© + Suzukii trap©	2.3500	0.7500	0
Pherocom© + Pherocom SWD© Dual-Lure©	8.8500	0.7800	0

A similar trend was observed in the DTF index for *Z. indianus*, with high population prevalence recorded when using the food baits Suzukii trap© and Pherocom SWD© Dual-Lure© across all traps tested **(Table 2)**. The highest DTF index was obtained when Handmade plastic jar traps were paired with Pherocom SWD© Dual-Lure© bait. Cera Trap© did not yield a calculable DTF index, regardless of the trap used **(Table 2)**.

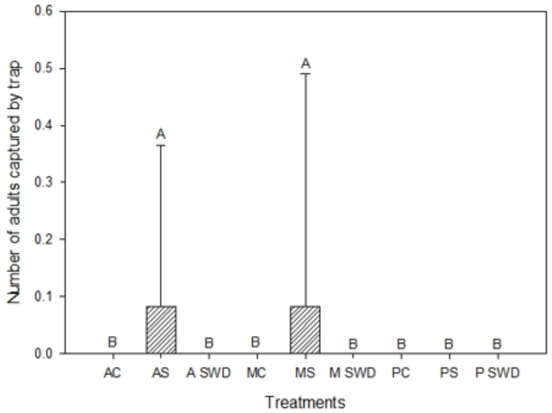
Second trial

Traps and food baits

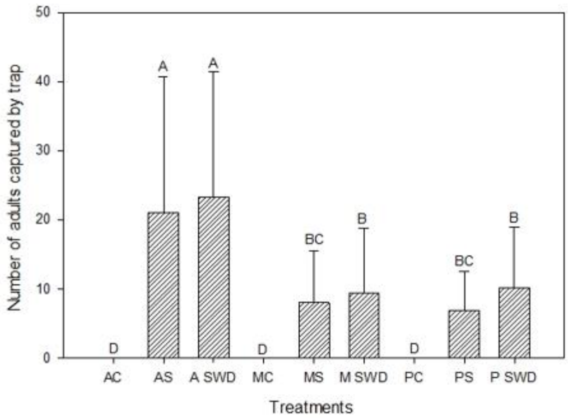
In the 2nd trial, the total number of captures was lower than in the first, with 1,899 specimens collected. Among these, only four were *D. suzukii* (0.2%), while the remaining 1,895 were identified as *Z. indianus*. All *D. suzukii* individuals were captured using handmade plastic jars or Multilure© traps baited with Suzukii Trap©, showing no significant differences **(Figure 2a)**.

For *Z. indianus*, the type of trap used influenced the capture numbers. Handmade plastic jar traps baited with Suzukii Trap© or Pherocom SWD© Dual-Lure© captured more than 100% of the specimens compared to other treatments **(Figure 2b)**.

As in the first trial, Cera Trap® did not capture any specimens.



a)



b)

Figure 2. *D. suzukii*, a) and *Z. indianus*, b) were captured in a combination of three traps and food baits in Ficus, Mexico (July-August 2019); AC: Handmade trap + Cera Trap©, AS: Handmade trap+ Suzukii© trap, ASWD: Handmade trap + Pherocom SWD© Dual-Lure©, MC: Multilure© trap + Cera Trap©, MS: Multilure© trap + Suzukii© trap, MSWD: Multilure© trap + Pherocom SWD© Dual-Lure©, PC: Pherocom© trap + Cera Trap©, PS: Pherocom© trap + Suzukii© trap, and PSWD: Pherocom© trap + Pherocom SWD© Dual-Lure©.

The effectiveness of the handmade plastic jar trap is likely due to the combination of 2 key factors: the perforations and the color. The 4 mm holes surrounding the jar allow the food bait to disperse into the environment while facilitating the entry of fruit flies. In contrast, the Pherocom© trap features two large lateral openings covered by a plastic mesh with a two mm diameter, which might make it harder for flies to enter directly. On the other hand, the Multilure© trap has a wide opening at the bottom and a yellow base. While the dimensions of the opening may ease the flies' entry, they could also make it easier for them to escape if the retention mechanism is inadequate. As noted earlier [32], increasing the entry area of traps can reduce their capture efficiency and overall performance [29]. Another concern is the potential to capture non-target species, such as other Diptera or larger arthropods [32]. The handmade plastic jar traps have smaller entry points, which may offer a selective advantage over the other traps by reducing captures of non-drosophilid flies [29].

Although red is thought to be appealing for attracting *D. suzukii* adults [29], which aligns with the red base of the handmade trap, other researchers suggest that different colors might produce a stronger attraction response [33, 34]. It appears that further investigation into color variations for optimal attraction is still needed.

The two drosophilid species exhibited distinct responses to the tested baits. *D. suzukii* was predominantly attracted to Suzukii trap®, while *Z. indianus* showed a preference for Pherocom© SWD Dual-Lure®. *D. suzukii* is particularly drawn to fermented substances like vinegar and wine, as well as certain yeasts [29]. Suzukii trap® contains enriched protein substances that elicit a strong attraction in *D. suzukii*, making it suitable for mass trapping of this fruitfly [35]. In contrast, *Z. indianus* favors juices, wines, and vinegar [34, 36], responding well to Pherocom© SWD Dual-Lure® [37], which is made from volatile compounds found in wine and vinegar (such as acetic acid, ethanol, acetone, and methanol) [38]. Both drosophilid species showed no attraction to Cera trap®, likely because it was initially developed and tested for Ceratitis capitata Wiedeman and is now used primarily for Anastrepha species [39]. Based on these findings, Suzukii trap® and Pherocom© SWD Dual-Lure® are recommended for use, while Cera trap® should be excluded as a bait for these 2 drosophilid species. Selecting the ideal trap and bait for fruit flies remains an ongoing challenge [40], as new options continue to emerge, offering local growers more effective trapping systems.

DTF index

The population density observed during the second trial influenced the calculation of the DTF index (n n). Only two treatments allowed for the calculation of the index: Handmade plastic jar with Suzukii trap© and Multilure© trap with Suzukii trap© bait, both showing a high prevalence range (0.0300-0.0700). For the remaining treatments, *D. suzukii* was not present in the study area during this period **(Table 3)**.

Table 3. Day trap flies (DTF) population prevalence index, showing the maximum and minimum values calculated for *D. suzukii* using various traps and food baits in figs from Morelos, Mexico (July-August 2019).

Treatment (trap plus food bait)	Maximum prevalence level	Minimum prevalence level	Weeks with prevalence values of 0.0000
Handmade + Cera trap©	0.0000	0.0000	6
Handmade + Suzukii trap©	0.0300	0.0000	4
Handmade + Pherocom SWD© Dual-Lure©	0.0000	0.0000	6
Multilure© + Cera trap©	0.0000	0.0000	6
Multilure© + Suzukii trap©	0.0700	0.0000	5
Multilure© + Pherocom SWD© Dual-Lure©	0.0000	0.0000	6
Pherocom© + Cera trap©	0.0000	0.0000	6
Pherocom© + Suzukii trap©	0.0000	0.0000	6
Pherocom© + Pherocom SWD© Dual-Lure©	0.0000	0.0000	6

Table 4. Day trap flies (DTF) population prevalence index, presenting the maximum and minimum values calculated for *Z. indianus* using different traps and food baits in figs from Morelos, Mexico (July-August 2019).

Treatment (trap plus food bait)	Maximum prevalence level	Minimum prevalence level	Weeks with prevalence values of 0.0000
Handmade + Cera trap©	0.0000	0.0000	6
Handmade + Suzukii trap©	5.4600	1.8200	0
Handmade + Pherocom SWD© Dual-Lure©	5.3900	1.0350	0
Multilure© + Cera trap©	0.0000	0.0000	6
Multilure© + Suzukii trap©	1.6700	0.4600	0
Multilure© + Pherocom SWD© Dual-Lure©	2.2500	0.8500	0
Pherocom© + Cera trap©	0.0000	0.0000	6
Pherocom© + Suzukii trap©	1.7800	0.4600	0
Pherocom© + Pherocom SWD© Dual-Lure©	2.4600	0.0000	1

A high prevalence was observed for *Z. indianus* across all traps and food baits used, except Cera Trap©. The handmade jar trap yielded the highest index values, showing comparable results when paired with Suzukii trap© or Pherocom SWD© Dual-Lure© **(Table 4)**. In this case, the DTF index was two to three times greater than in other treatments.
The DTF index demonstrated a significant prevalence of both *D. suzukii* and *Z. indianus*, indicating that the fig-growing region offers favorable conditions for the ongoing reproduction of these species [7]. This underscores the need for regional coordination and initiatives to manage populations and mitigate potential damage caused by these fruit flies.

Conclusion

D. suzukii Matsumura and *Z. indianus* Gupta are 2 fruit fly species that pose economic threats to fig cultivation in Morelos, Mexico, where the environment favors their population growth. According to the results of this study, the most effective approach for monitoring adult drosophilid populations involves the use of handmade plastic jar traps with Suzukii trap® or Pherocom© SWD Dual-Lure© as bait.

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Conflict of Interest: None

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Ethics Statement: None

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