

Mango (*Mangifera indica*) orchard fruit fly population dynamics and correlation matrix with host factors and weather

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Article Info

Received: 29-12-2024 Revised: 15-02-2025 Accepted: 18-02-2025 Published: 21-02-2025

ABSTRACT

In order to analyze the population dynamics of fruit fly (*Bactrocera dorsalis*) species after placing the necessary number of methyl eugenol traps (@6 per acre), the current study was conducted in the mango orchards at the Indian Agricultural Research Institute, New Delhi, in 2020–2021 and 2021–2022. Fruit fly numbers were tracked every week and associated with a number of meteorological factors. The oriental fruit fly was found to be the most common and plentiful of the fruit fly species, followed by *B. zonata*, *B. correcta*, and *B. cucurbitae*. In mango farms, fruit fly numbers peaked in June and July, which also happened to be the season of ripening, humidity, and precipitation. Fruit fly population dynamics have been discovered to be influenced by a variety of variables, such as weather, the availability of preferred host plants and alternative hosts, and fruit qualities. Male fruit fly seasonal trap catches exhibited a maximal but substantial positive association with the lowest temperature (0.701**) and a moderately significant negative correlation (-0.612*). Fruit fly population variations were shown to be positively correlated with relative humidity ($r = 0.924^{**}$) and rainfall ($r = 0.721^{**}$) at all orchard locations under observation.

Keywords: Diversity, Fruit flies, Host, Mango, Maturity, Traps

Introduction

Known as the "king of fruits," the mango (*Mangifera indica* L.) has great cultural and historic significance in India. With export volumes of 27,872.78 metric tons valued at ₹327.45 crores (44.05 US\$) million in 2021–2022, it is the biggest producer and a major exporter of fresh mangoes. Even though India is the world's top producer of mangos, the main obstacle to exports is the pest infestation of fruit flies, stone weevils, and other pests. By directly damaging fruit and enforcing strict quarantine regulations, these pests result in significant losses. Approximately 200 species of fruit flies, or 5% of the world's known tephritid fauna, are found in India. Not all fruit fly species are pests, however, since only 35–40 species have been linked to their host plants either directly or indirectly. *Bactrocera dorsalis* (Hendel), *Bactrocera zonata* (Saunders), *Bactrocera correcta* (Bezzi), and *Bactrocera cucurbitae* (Coquillett) are important fruit fly species (Kapoor 2002, Verghese et al. 2002, Choudhary et al. 2012). Mangoes in India are being threatened by *Bactrocera dorsalis*.

Fresh fruit exports from a number of tropical and subtropical nations are hampered. Mango fruit damage is now also linked to the peach fruit fly (*B. zonata*) and the guava fruit fly (*B. correcta*) (Kapoor 2002). Because of their polyphagous nature, high reproductive capability, adaptability to various agroclimatic areas, and protection of their larvae under the fruit pulp tissue, these fruit fly species are difficult to manage. The emphasis has turned to Integrated Pest Management (IPM) methods because to the growing demand for pesticide-free fruits worldwide. Monitoring the pest population with the Male Annihilation Technique (MAT), which combines a pesticide incorporated in an appropriate substrate with the para-pheromone methyl eugenol, is one popular IPM technique. Seasonal variations in rainfall (intensity and distribution), relative humidity, and minimum temperature during fruit maturity (Vayssieres et al. 2005, Verghese et al. 2006, Vayssieres et al. 2009, Migani et al. 2014, Patel and Das 2021) all have an impact on fruit fly species diversity and abundance (Salazar-Mendoza et al. 2021, Rasolofoarivao et al. 2022). Fruit flies are most prevalent during the ripening season. Thus, modifying the harvest date may be a useful tactic to reduce the danger of infection (Grechi et al. 2021). In addition to environmental variables

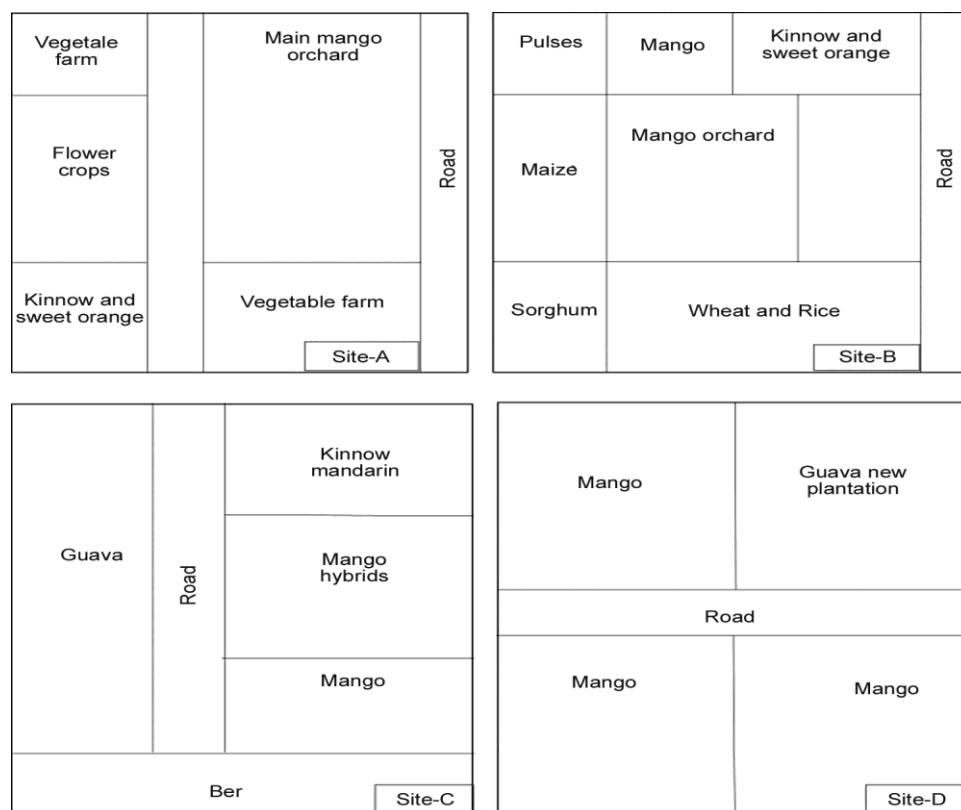
Considering genetic characteristics, the presence of nearby alternative hosts, which sustain their life cycle and ongoing reproduction, has a significant impact on fruit fly population changes (Badii et al. 2015). In light of these considerations, the research was carried out in the mango orchards at IARI, New Delhi from 2020–2021 to 2021–2022 to investigate the interaction between fruit fly population dynamics, weather parameters, host crops, and fruit maturity.

MATERIALS AND METHODS

The Mango Field Gene Bank of the Division of Fruits and Horticultural Technology, ICAR-Indian Agricultural Research Institute (IARI), New Delhi, India, was the site of the present fruit fly survey and monitoring. Because host crops have a significant effect on the variety and abundance of diverse fruit fly species, they were taken into consideration while choosing experimental orchards in different agro-ecosystems. Four distinct mango orchards were included in the research; sites A, B, C, and D were 16, 9, 5, and 3.5 acres, respectively. Fig. 1 provides detailed descriptions of the locations encompassed by several alternative host crops. (i) Amrapali (AM), Baganapalli (BP), Bombay Green (BG), Chausa (CH), Dashehari (DS), Langra (LG), Mallika (ML), Neelum (NL), Olour (OL), Tommy Atkins (TA), Totapuri (TP), and other hybrids are among the commercial mango genotypes found in Site-A, the mixed orchard. A variety of fruit crops, including papaya, Kinnow mandarin, sweet orange, grapefruit, and pumello, as well as vegetable crops, such as cucurbits (gourds, melons, squash, and others), solanaceous crops (tomato and chilli), and legumes (peas and beans), surround this block. (ii) Site-B is a mixed orchard with mango hybrids [Pusa Arunima (PAR), Pusa Lalima (PLM), Pusa Manohari (PMN), Pusa Peetamber (PPT), Pusa Pratibha (PPR), Pusa Shreshth (PSR), and Pusa Surya (PSU)] encircled by field crops (wheat, rice, sorghum), melons, squash, and other crops. (iii) On the other hand, Site-C was likewise a mixed orchard with IARI mango hybrids and several tree-host fruit crops such papaya, citrus (Kinnow mandarin, guava, sweet orange, lemon), and ber (Zizyphus sp.). In order to eradicate the presence of other crop hosts near the bearing mango genotypes, the fourth Site-D contained just the target crop, mango.

A plastic white jar measuring 15 cm by 10 cm was used to hand create methyl eugenol traps (ICAR-IIHR) for fruit fly monitoring. To enable rainwater to drain, round holes measuring 0.5 cm by 3.0 cm were punched on the jar's sides and bottom. Ethyl alcohol (99.9% AR), methyl eugenol, and spinosad (45.0% sc) were combined in a 6:4:1 ratio to create the lure solution. To guaranty full absorption, 5 cm × 5 cm × 2 cm jute-covered plywood pieces were immersed in the solution for 48 hours. A wire hook was used to secure the lure-soaked plywood blocks to the top of the trap after 48 hours. Each acre has six traps suspended two meters above the ground. Throughout the fruiting season, which ran from May to August, observations were made every week. Concurrently, meteorological data

Fig 1 Crop diversity in each mango orchards (Site-A, B, C- mixed orchards and Site-D - homogenous orchard).



including maximum and minimum temperatures ($^{\circ}\text{C}$),

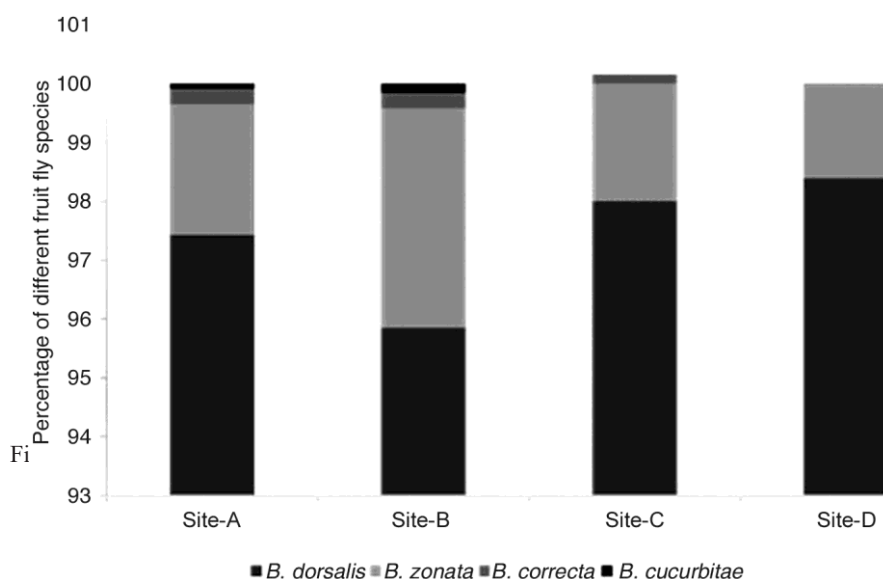
rainfall (mm), relative humidity (%), and sunshine duration

(h) were collected from the Meteorological Section of the institute. The mean values of these weather parameters were calculated for each standard meteorological week (SMW) to examine the correlation between weather conditions and the average fruit fly catches. The collected fruit flies were stored in vials and transported to the Laboratory of the Division of Entomology, ICAR-IARI, New Delhi, for species identification. The experiment followed a randomized block design (RBD) with three replications per treatment. Data analysis was carried out statistically using SPSS 16.0 software. Pearson's simple correlation was used to calculate the relationship between male fruit fly catches per week and weather parameters, with significance levels set @ $P < 0.01$ and $P < 0.05$.

RESULTS AND DISCUSSION

Fruit fly abundance: *B. dorsalis*, *B. zonata*, *B. correcta*, and *B. cucurbitae* were the most common fruit fly species found. With 97.41% of the catches, *B. dorsalis* was the most often captured species, followed by *B. zonata* at 2.39%, *B. correcta* at 0.17%, and *B. cucurbitae* at 0.06% (Fig 2). During the fruiting seasons, these four species' distribution fluctuated across the four orchards with both homogenous and diverse fruit harvests.

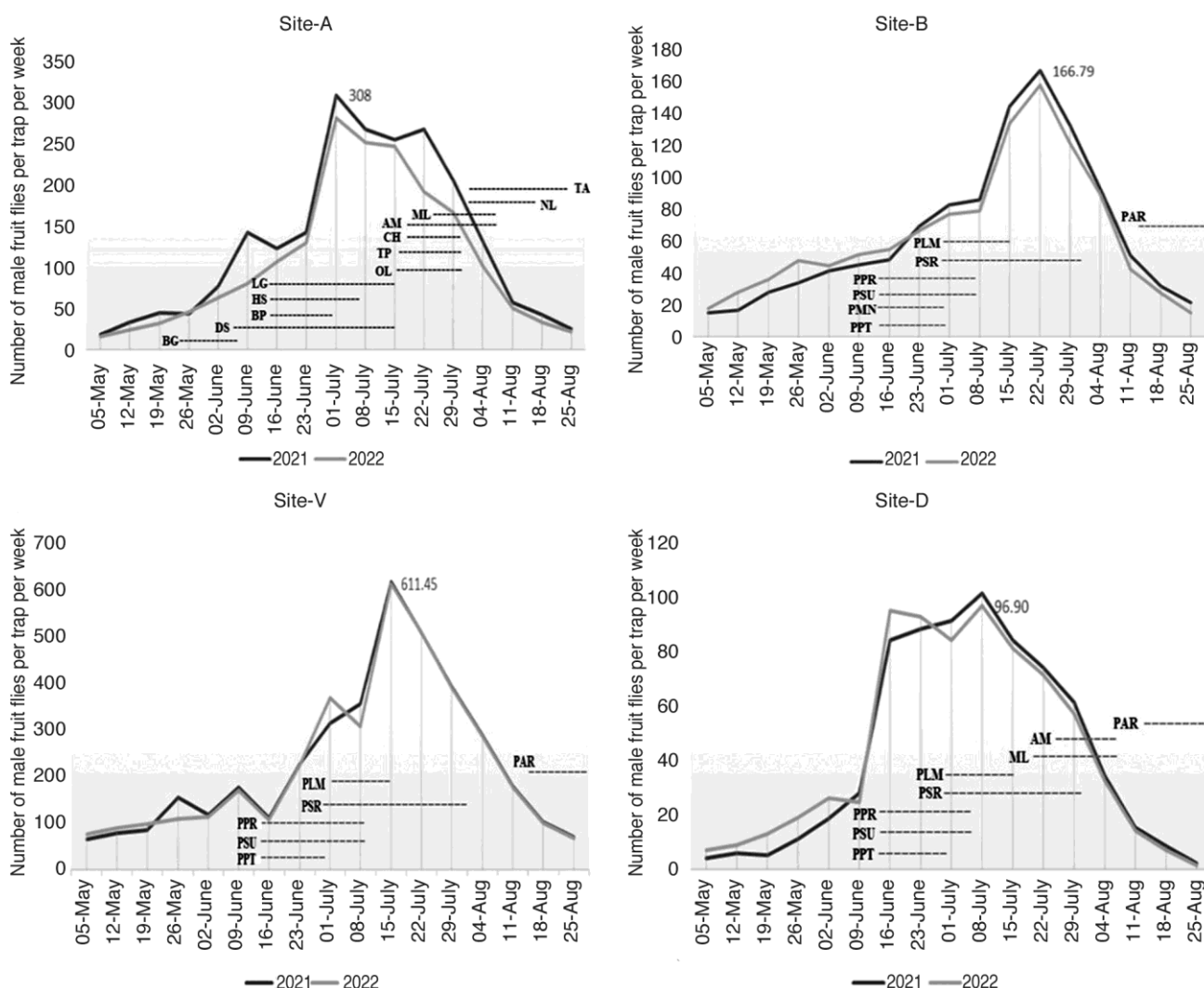
All four species were caught in the traps in heterogeneous orchards (Sites A, B, and C), with the exception of *B. cucurbitae* at Site C, where the host species (cucurbits) was absent from the surrounding region. With a range of 95.4–98.38%, *B. dorsalis* essentially became the most prevalent species in diverse orchards, followed by *B. zonata* (3.7–1.61%), *B. correcta* (0.27–0.14%), and *B. cucurbitae* (0.15–0.08%). In contrast, just two species were found in the homogenous mango orchard (Site D), with *B. dorsalis* making up 98.38% of the flies and *B. zonata* making up 1.61%.



The most common and polyphagous species is *dorsalis*, which may use a variety of fruit trees and vegetables as hosts that are accessible all year round (Mwatawala et al. 2009, Badii et al. 2015, Rasolofoarivao et al. 2022, Susanto et al. 2022). **Fruit fly population dynamics:** The amount of fruit flies caught each week varied significantly, according to the population fluctuation pattern of fruit flies assessed in homogeneous and mixed mango orchards. The average weekly fruit fly catches in all chosen orchards and the fruit maturation time for various mango genotypes are shown in Fig. 3. In the first week of May, the average number of male fruit flies captured per trap at Site A, where commercial types are produced, was just 18. By the end of May, the numbers had steadily risen to 45 flies per trap. Beginning in the first week of June, the average number of adult flies caught each trap increased significantly, peaking at 135.83 insects per trap at the end of the month. Fruit fly catches rose when the wet season started, peaking at 308 insects per trap every week at the beginning of July, when most mango kinds achieved maturity. But by early August, the adult population started to steadily diminish, with an average of 77.5 flies per trap in the first few weeks and 23 flies per trap in the last week, which corresponded to a drop in fruit availability.

Similarly, the similar trend line was seen at Site B, where fly density was initially low from May to the beginning of June

before steadily increasing from the beginning of July to the end of July. This tendency may be explained by the novel hybrid mango genotypes' late maturation. The population then started to drop by the end of August. Similarly, compared to all other orchards, fruit fly population densities were greater in Site C, where hybrids are planted. But in July, the growth was faster, leading to the biggest adult population of fruit flies, topping all other orchards with a weekly peak of 611.45 insects per trap. Because there were sufficient hosts for the fruit flies, the population continued to be significant even in August. Fruit flies may also use the fallen fruits in the mango orchards as nesting grounds. The Oriental fruit fly, *B. dorsalis*, predominated in the homogenous mango orchard (Fig. 3), followed by *B. zonata*. Fruit fly population dynamics: The number of insects caught on a weekly basis varied significantly, according on the population fluctuations pattern of fruit flies assessed in homogeneous and mixed mango orchards. The average weekly fruit catches are shown in Figure 3.



flies in all selected orchards

Fig 3 Population fluctuations of male fruit flies/trap/week in mixed (Site-A, B, and C) and homogenous mango orchards during 2020–2021 to 2021–2022.

and fruit maturity time in various genotypes of mangos. In comparison to other mixed orchards, the initial weekly capture of male fruit flies was low at Site A, where commercial varieties are grown. The average number of flies captured per trap per week was quite low in May, but the fruit fly population gradually increased to over 100 males captured per trap per week in July. The lack of alternative hosts and varietal variations may be the cause of the reduced fly capture in homogeneous orchards. Sarada et al. (2001) previously noted that, in Tirupati, Andhra Pradesh, the peak fly population in mango orchards occurred between May and July, which coincided with the local fruit maturation period. Additionally, Vayssieres et al. (2009) investigated the dynamics of fruit fly populations in two

Table 1 Correlation between total male fly catches per week and weather parameters

Parameter	Fruit fly catches	Tmax (°C)	Tmin (°C)	RH (M)	RH (E)	RF (mm)	Sunshine (h)
Fruit fly catches	1.000						
Tmax (°C)	-0.672*	1.000					
Tmin (°C)	0.701*	0.257	1.000				
RH (M)	0.565	-0.971**	-0.382	1.000			
RH (E)	0.924**	-0.835**	0.083	0.757*	1.000		
RF(mm)	0.721**	-0.472	0.353	0.440	0.772*	1.000	
Sunshine (h)	-0.449	0.839**	-0.020	-0.722*	-0.697*	-0.392	1.000

**Significant at $P \leq 0.01$; * Significant at $P \leq 0.05$. RH, Relative humidity; RF, Rainfall.

B. dorsalis was shown to be the prevalent species throughout the whole mango season, infesting the several genotypes during their individual ripening dates, regardless of the orchards. In a similar vein, Bansode and Patel (2018) reported from South Gujarat that June saw the greatest number of *B. dorsalis* adults captured, suggesting a local peak in the fly population. Abiotic factors and population fluctuations: Table 1 shows the relationship between abiotic factors and fruit fly population dynamics across all orchards. Following the first rains in June (3.7 mm in 2021; 0.85 mm in 2022) and a notable rise in rainfall in mid-July (34 mm in 2021; 13.88 mm in 2022), fruit fly species populations abruptly surged in all orchards. Male fruit fly seasonal trap catches in our target areas exhibited a maximal but substantial positive connection with the lowest temperature (0.701**) and a moderately significant negative correlation (0.672*). At a significance threshold of $P < 0.01\%$, there was, nevertheless, a substantial positive connection with rainfall ($r = 0.721^{**}$) and relative humidity (E) ($r = 0.924^{**}$). Abiotic variables including temperature and rainfall have a substantial impact on fruit fly dispersion (Duyck et al. 2006) and population dynamics (Jayanthi and Verghese 2011), according to several research in the literature. Abiotic parameters, such as times of minimum temperature (Verghese et al. 2006) and the start of precipitation (Sarada et al. 2001; Vayssieres et al. 2009; Salazar-Mendoza et al. 2021), have been shown to positively correlate with *B. dorsalis* populations. Fruit flies may pupate in the soil thanks to rainfall, which moistens the soil and produces favorable circumstances for adult emergence (Kamala Jayanthi and Verghese 2000).

Fruit maturity and population dynamics: Fruit flies mainly harm mid-season and late genotypes, as shown by the larger numbers of fruit flies from the end of June to the beginning of July, which corresponds with the ripening phase (Fig. 3) of the major mango genotypes. Early genotypes may have survived the infection by then since fruit fly populations only emerge in June and July with the start of pre-monsoon showers or regular monsoon rainfall. The mango fruiting season and farmers depend on the synchronization of high fly pest population with fruit maturation due to the intimate association between fruit flies and mango trees (Vayssieres et al. 2009). For mid-season and late-maturing mango genotypes in particular, it is not unexpected to see the largest fly numbers throughout the maturity phase; these counts are also highly connected with daily rainfall (Vayssieres et al. 2014).

Population dynamics and hosts: The ripening times of the several host crops that surround the major mango orchards are shown in Table 2. Fruit flies may complete their life cycle continuously since there are adequate host horticulture crops accessible all year long. *B. dorsalis* first appeared in mangoes and other fruits including guava, papaya, lemon, and cucurbits between May and August. Fruit flies maintained their life cycle on the rainy season crop of guava from September to October. After October, they were seen on most of the fruiting host plants in the orchards that were chosen. Fruit flies were mostly seen on several citrus species from November to February, including mandarin (*Citrus deliciosa*), orange (*Citrus sinensis*), grapefruit (*Citrus paradisi*), pummelo (*Citrus maxima*), and Kinnow mandarin, in addition to guava (*Psidium guajava*) observations in November. Fruit flies were most prevalent on ber (*Zizyphus* sp.) fruits in March. From May onward, the fly population continued to infest a variety of host plants (fruit and vegetable crops), including 11 fruit species from seven botanical families and vegetables from two families.

Fruit flies were more prevalent in the mixed orchard than in the homogeneous one, perhaps as a result of varietal variations and the availability of diverse hosts with varying fruit maturation times throughout the year. All four species—*B. dorsalis*, *B. zonata*, *B. correcta*, and *B. cucurbitae*—were seen in the mixed orchard, but *B.* was absent from the homogeneous orchard. Table 2 Fruit maturity period of different host fruit and vegetables crops surrounding the mango orchards (Site-A, B and C) under North Indian conditions

Crop	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Ber									+	+	+	
Cucurbits		+	+	+				+	+			

Grapefruit					+	+	+	+
Guava		+	+		+			
Kinnow						+	+	+
Lemon			+	+				
Mango	+	+	+	+				
Papaya		+	+	+				
Pummelo						+	+	+
Sweet orange					+	+	+	
Solanaceous crops		+	+	+				

correcta and *B. cucurbitae* are caused by the absence of host plant species in that specific orchard. Both biotic and abiotic factors, such as host plants, are responsible for the reported rise in fruit fly variety and abundance (Tan and Serit 1994, Aluja and Mangan 2008, Jayanthi and Verghese 2011, Migani et al. 2014, Rasolofoarivao et al. 2022). Celedonio-Hurtado et al. (1995) found that host plants that bridge populations at times when the principal hosts are unavailable are often linked to the seasonality of fruit flies. Other species, such as the West Indian fruit fly *Anastrepha obliqua*, the Mexican fruit fly *Anastrepha ludens* (Aluja et al. 1996), and *B. dorsalis* (Tan and Serit 1994), have also shown a relationship between fruit availability and fruit fly populations. Thus, another important element that contributes to these population variations is the presence of wild hosts near the orchards (Vayssieres et al. 2009, Badii et al. 2015). Four tephritid species, which are often found in mango orchards and are well-known for infesting mangoes, have substantial economic importance among the species under observation. Following the first significant rainfall, population density levels increased, underscoring the critical significance of environmental elements in the invasion process and confirming that rainfall may be used as a short-term indication for fruit fly population prediction. The year-round presence of planted horticultural crops and other host plants is likely to support fruit fly abundance. Accurate and trustworthy information on the species involved and the variety of hosts they infest is essential for fruit fly management. Our findings imply that the observed trends might have been caused by a number of variables, including variations in ambient circumstances, nutritional content, fruit defense chemicals, and the availability of substitute host plants. One useful tactic for lowering the chance of infection is to change the harvest date. To fully comprehend these possible pathways and create long-term management plans against these economically important pests, further study is required.

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