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Population dynamics of fruit flies and correlation matrix with weather and host variables in mango (*Mangifera indica*) orchards

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ABSTRACT

The present study was carried out in the Mango orchards at Indian Agricultural Research Institute, New Delhi during 2020–2021 and 2021–2022 and aimed at analysing the population dynamics of fruit fly (*Bactrocera dorsalis*) species after putting the requisite number of methyl eugenol traps (@6 per acre). Weekly monitoring of fruit fly populations was performed and correlated with various weather parameters. Among the fruit fly species, the oriental fruit fly was found to be the most prevalent and abundant, followed by *B. zonata*, *B. correcta*, and *B. cucurbitae.* Fruit fly populations peaked in mango plantations between June and July, coinciding with the ripening time and the occurrence of humid conditions and rainfall. Multiple factors, including weather conditions, the presence of preferred host plants, and alternative hosts, fruits characteristics were found to influence the dynamics of fruit fly populations. The seasonal trap captures of male fruit flies showed a moderately significant negative correlation (-0.612^{*}) with maximum but significant positive correlation with the minimum temperature (0.701^{**}). However, a positive correlation was observed between relative humidity ($r = 0.924^{**}$) and rainfall ($r = 0.721^{**}$) with the fluctuations of fruit fly populations across all the monitored orchard sites.

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

Mango (*Mangifera indica* L.), hailed as the king of fruits, holds significant cultural and traditional value in India. It stands as the largest producer and a prominent exporter of fresh mangoes, with export volumes reaching 27,872.78 metric tonnes valued at ₹327.45 crores (44.05 US$) million during the year 2021–22. Despite India's status as the leading mango producer, export opportunities are constrained primarily due to pest infestation of fruit fly, stone weevil, etc. which are the major impediment in the exports. These pests cause substantial losses through direct fruit damage and the imposition of stringent quarantine measures. India harbours about 5% of the world's known tephritid fauna, encompassing approximately 200 species of fruit flies. However, only 35–40 species have been found to be directly or indirectly associated with their host plants, indicating that not all fruit fly species are pests. Among the various fruit fly species, *Bactrocera dorsalis* (Hendel), *B. zonata* (Saunders), *B. correcta* (Bezzi), and *B. cucurbitae* (Coquillett) hold significant importance (Kapoor 2002, Verghese *et al*. 2002, Choudhary *et al*. 2012). *Bactrocera dorsalis* poses a major threat to mangoes in India and several tropical and sub-tropical countries hindering their export of fresh fruits. Currently, both the peach fruit fly (*B. zonata*) and the guava fruit fly (*B. correcta*) have also become associated with mango fruit damage (Kapoor 2002). Managing these fruit fly species pose challenges due to their polyphagous nature, high reproductive capacity, ability to adapt to different agro-climatic regions, and also protection of their maggots beneath the fruit pulp tissue. With the increasing demand for pesticide-free fruits globally, the focus has shifted towards Integrated Pest Management (IPM) techniques. One commonly used IPM method is monitoring the pest population through the Male Annihilation Technique (MAT), which involves the use of methyl eugenol, a para-pheromone, along with an insecticide embedded in a suitable substrate. The abundance and diversity of fruit fly species are influenced by seasonal variations, particularly for rainfall (intensity and distribution) and relative humidity (Salazar-Mendoza *et al*. 2021, Rasolofoarivao *et al*. 2022) as well as minimum temperature prevailing at the time of fruit maturity (Vayssieres *et al*. 2005, Verghese *et al.* 2006, Vayssieres *et al.* 2009, Migani *et al*. 2014, Patel and Das 2021). The peak population of fruit flies is observed during the ripening period. Therefore, adjusting the timing of harvest can be an effective strategy to mitigate infestation risks (Grechi *et al*. 2021). Apart from environmental factors

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and genetic traits, fruit fly population variations are much influenced by the existence of neighbouring alternate hosts, which support their life cycle and continuous reproduction (Badii *et al*. 2015). Considering these factors, the study was conducted in the mango orchards at IARI, New Delhi during 2020–2021 to 2021–2022 to examine the relationship between fruit fly population dynamics, weather parameters, host crops and fruit maturity.

MATERIALS AND METHODS

The current survey and monitoring of fruit flies were carried out at the Mango Field Gene Bank of the Division of Fruits and Horticultural Technology, ICAR-Indian Agricultural Research Institute (IARI), New Delhi, India. The selection of experimental orchards took into account the influence of host crops in various agro-ecosystems, as they strongly impact the diversity and abundance of different fruit fly species. The study included four mango orchards situated in different locations and sites of A, B, C, and D were 16, 9, 5, and 3.5 acres, respectively. Detailed descriptions of the sites surrounded by different alternate host crops have been shown in Fig 1. (i) Site-A, the mixed orchard comprising of various commercial mango genotypes such as Amrapali (AM), Baganapalli (BP), Bombay Green (BG), Chausa (CH), Dashehari (DS), Langra (LG), Mallika (ML), Neelum (NL), Olour (OL), Tommy Atkins (TA), Totapuri (TP), as well as some hybrids. This block is surrounded by different fruit crops such as papaya, Kinnow mandarin, sweet orange, grapefruit, pumello, and vegetable crops including cucurbits (gourds, melons, squash, and others), Solanaceous crops (tomato and chilli), and legumes (peas and beans). (ii) Site-B is the mixed orchard consisting of mango hybrids [Pusa Arunima (PAR), Pusa Lalima (PLM), Pusa Manohari (PMN), Pusa Peetamber (PPT), Pusa Pratibha (PPR), Pusa Shreshth (PSR), Pusa Surya (PSU)] surrounded by a citrus orchard (sweet orange, Kinnow mandarin, and pumello), field crops (wheat, rice, sorghum), and others (melons, squash, Solanaceous crops). While, (iii) Site-C was also a mixed orchard, which included IARI mango hybrids and different tree host fruit crops such as ber (*Zizyphus* sp.), citrus (Kinnow mandarin, guava, sweet orange, lemon), and papaya. The fourth Site-D had only the target crop, i.e. mango, aiming to eliminate the presence of other crop hosts in the vicinity of the bearing mango genotypes.

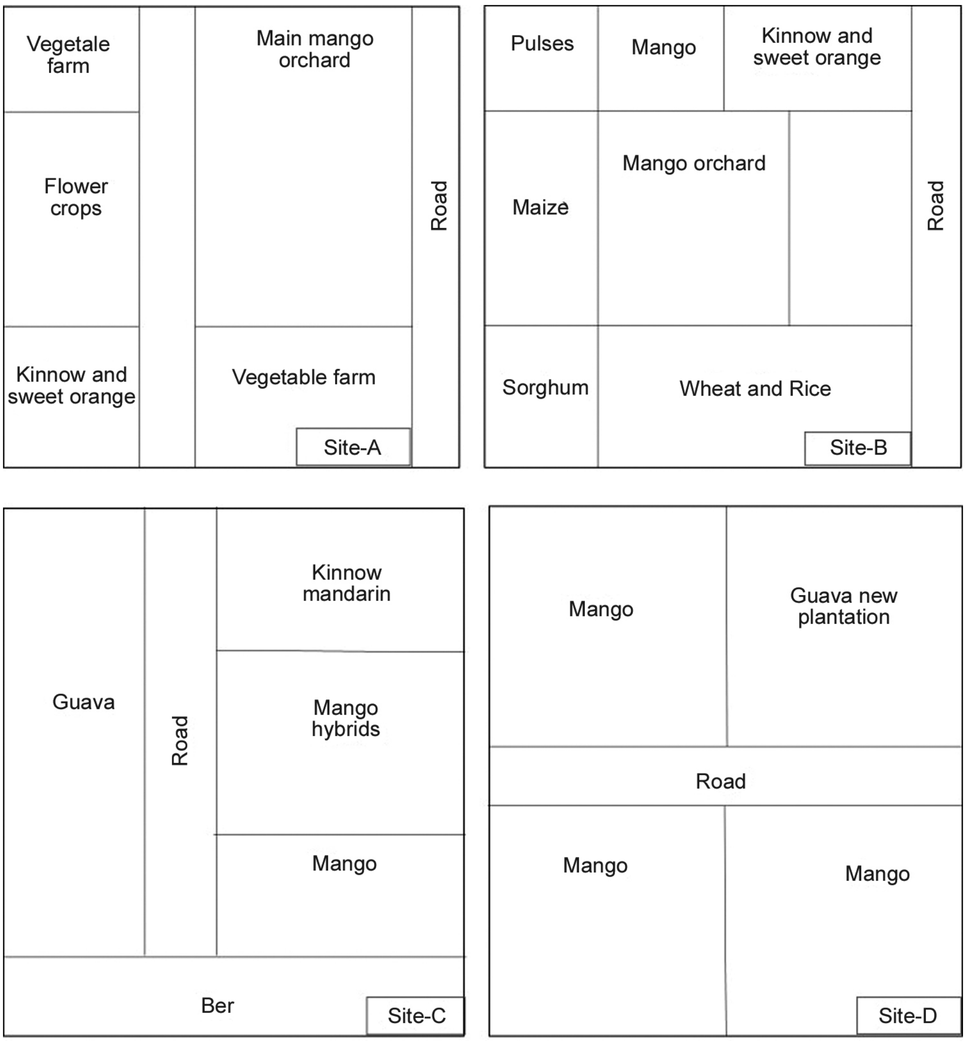

Fig 1 Crop diversity in each mango orchards (Site–A, B, C- mixed orchards and Site–D - homogenous orchard).

To monitor the fruit flies, methyl eugenol traps was manually prepared (ICAR-IIHR) using a polyethylene white jar (15 cm × 10 cm). Round holes (0.5 cm × 3.0 cm) were punctured on sides of the jar and at the bottom of the jar to allow drainage of rainwater. Lure solution was prepared by combining ethyl alcohol (99.9% AR), methyl eugenol, and spinosad (45.0% SC) in a ratio of 6:4:1. Jute-covered plywood blocks measuring 5 cm × 5 cm × 2 cm were soaked in the solution for 48 h to ensure complete absorption. After 48 h, the lure-soaked plywood blocks were attached to the top of the trap using a wire hook. A total of 6 traps per acre were hung 2 m above the ground level. Observations were taken on a weekly basis during the fruiting period, from May–August. Simultaneously, weather data including maximum and minimum temperatures (°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: The main fruit fly species observed were *B. dorsalis*, *B. zonata*, *B. correcta*, and *B. cucurbitae.* Among these, *B. dorsalis* was the most frequently trapped species, accounting for 97.41% of the captures, followed by *B. zonata* at 2.39%, *B. correcta* at 0.17%, and *B. cucurbitae* at 0.06% (Fig 2). The distribution of these four species varied between the four orchards with heterogeneous and homogeneous fruit crops during the fruiting seasons.

In heterogeneous orchards (Sites A, B and C), all four species were captured in the traps, except for *B. cucurbitae* at Site C, where the surrounding area lacked the host species (cucurbits). In heterogeneous orchards, *B. dorsalis* virtually became the most dominant species, ranging from 95.4–98.38%, followed by *B. zonata* (3.7–1.61%), *B. correcta* (0.27–0.14%), and *B. cucurbitae* (0.15–0.08%). On the contrary, in the homogeneous mango orchard (Site D), only two species were captured, with *B. dorsalis* accounting for 98.38% of the flies and *B. zonata* comprising 1.61%. In accordance with our work, it has been reported that *B. dorsalis* as a most widely distributed and polyphagous, capable of utilizing various fruit plants and vegetables as hosts, which are available throughout the seasons (Mwatawala *et al*. 2009, Badii *et al*. 2015, Rasolofoarivao *et al*. 2022, Susanto *et al*. 2022).

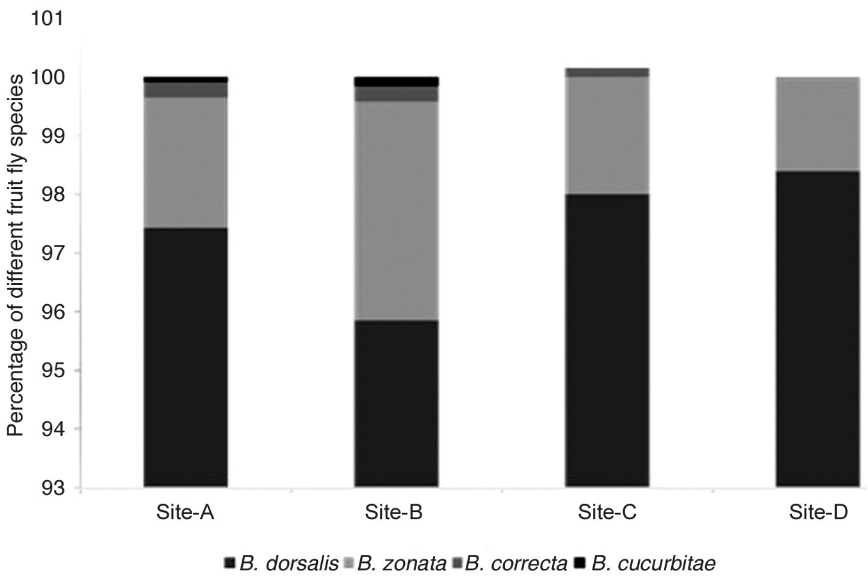

Fig 2 Fruit fly abundance in different mango orchards.

Population dynamics of fruit fly: The population fluctuations pattern of fruit flies evaluated in mixed and homogenous mango orchards showed a significant variation in the number of flies captured on a weekly basis. Fig 3 presents the average weekly captures of fruit flies in all selected orchards and fruit maturity period in different mango genotypes. At Site A, where commercial varieties are grown, the initial weekly capture of male fruit flies was low, averaging 18 flies per trap during the first week of May. The numbers gradually increased to 45 flies per trap by the end of May. The catches of adult flies exhibited a significant rise starting from the first week of June, with an average of 70 flies per trap, reaching a peak of 135.83 flies per trap by the last week of June. As the rainy season commenced, fruit fly captures increased further and reached their highest point (308 flies per trap per week) at the beginning of July, coinciding with the maturity of most mango varieties. However, by the beginning of August, the adult population began to decline gradually, with an average of 77.5 flies per trap in the initial weeks and decreasing to 23 flies per trap in the final week, corresponding to a decrease in the availability of fruits.

Likewise, at Site B, same trend line was recorded with low initial fly density from May to the beginning of June but gradually found to increase with the start of July to the end of July. This pattern can be attributed to the late maturing nature of the new hybrid mango genotypes. Subsequently, the population began to decline towards the end of August. Similarly, at Site C, where hybrids are planted, the population densities of fruit flies were higher as compared to all other orchards. However, the increase was more rapid in July, resulting in the highest adult population of fruit flies, peaking at 611.45 flies per trap per week, surpassing all other orchards. The population remained substantial even in August due to the availability of suitable hosts for the fruit flies. Additionally, the fallen fruits in the mango orchards could serve as breeding sites for fruit flies. In the homogeneous mango orchard (Fig 3), the dominant fruit fly species was the Oriental fruit fly, *B. dorsalis*, followed by *B. zonata*. The Population dynamics of fruit fly: The population fluctuations pattern of fruit flies evaluated in mixed and homogenous mango orchards showed a significant variation in the number of flies captured on a weekly basis. Fig 3 presents the average weekly captures of fruit flies in all selected orchards

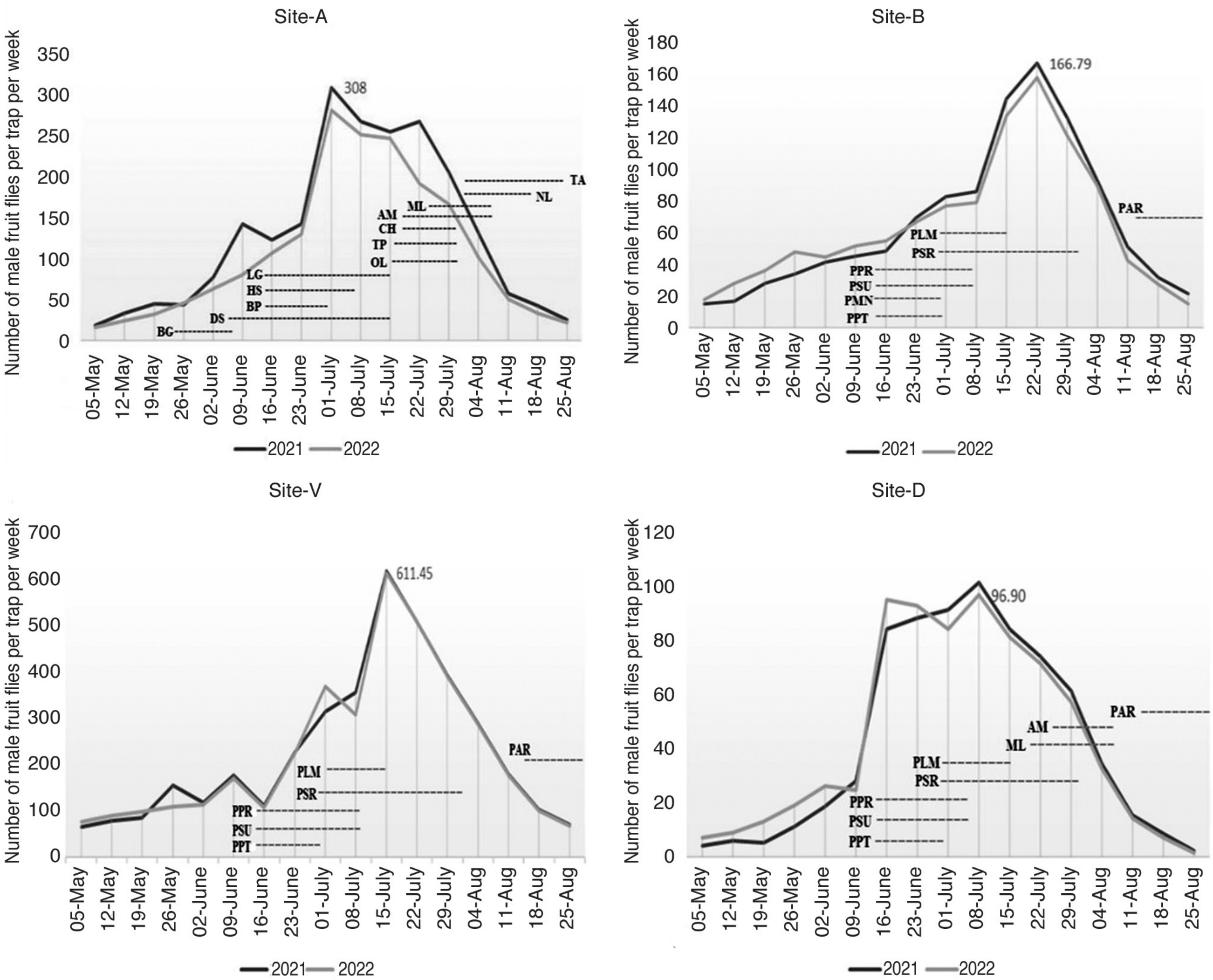

Fig 3 Population fluctuations of male fruit flies/trap/week in mixed (Site-A, B, and C) and homogenous mango orchards during 2020–2021 to 2021–2022.

and fruit maturity period in different mango genotypes. At Site A, where commercial varieties are grown, the initial weekly capture of male fruit flies was low, average number of flies captured per trap per week was quite low in May, though the fruit fly population showed a gradual increase of over 100 males captured per trap per week in July, but compared to other mixed orchards it is lower. The lower fly capture in homogenous orchard could be attributed towards the varietal differences and absence of alternate hosts. Earlier, Sarada *et al*. (2001) also mentioned that the peak fly population in mango orchards occurred from May–July, coinciding with the local fruit maturity period under Tirupati, Andhra Pradesh conditions. Vayssieres *et al*. (2009) also studied the fruit fly population dynamics 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)	0.92^{4*}*	-0.835**	0.083	0.757*	1.000		
RF(mm)	0.72^{1*}*	-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≤0.01; * Significant at P≤0.05. RH, Relative humidity; RF, Rainfall.

orchards where irrespective of the orchards *B. dorsalis* was found to be the predominant species during the entire mango season infesting the different genotypes at their respective ripening times. Similarly, Bansode and Patel (2018) reported from South Gujarat that the highest numbers of *B. dorsalis* adults were trapped in June, indicating a local peak in the fly population.

*Population fluctuations and abiotic variabl*es: Date in Table 1 presents the correlation between abiotic variables and the population dynamics of fruit flies catches of all orchards. The populations of fruit fly species suddenly increased in all orchards after the first rains in June (3.7 mm in 2021; 0.85 mm in 2022) and a significant increase in rainfall during mid-July (34 mm in 2021; 13.88 mm in 2022). The seasonal trap captures of male fruit flies in our target locations showed a moderately significant negative correlation (0.672^{*}) with maximum but significant positive correlation with the minimum temperature (0.701^{**}). However, there was a significant positive correlation with relative humidity (E) ($r = 0.924^{**}$) and rainfall ($r = 0.721^{**}$) at a significance level of $P \leq 0.01\%$. Numerous studies in the literature have firmly established the significant influence of abiotic factors, such as temperature and rainfall, on the distribution of fruit flies (Duyck *et al*. 2006) and population dynamics (Jayanthi and Verghese 2011). Similar studies have shown a positive correlation between abiotic factors and *B. dorsalis* populations, including periods of minimum temperature (Verghese *et al.* 2006) and the onset of precipitation (Sarada *et al*. 2001; Vayssieres *et al*. 2009; Salazar-Mendoza *et al*. 2021). The rainfall, which moistens the soil and creates favourable conditions for adult emergence, may facilitate the pupation of fruit flies in the soil (Kamala Jayanthi and Verghese 2000).

Population dynamics and fruit maturity: The higher populations of a fruit fly during June end to the beginning of July, coinciding with the ripening period (Fig 3) of the main mango genotypes indicate that fruit flies primarily damage mid-season and late genotypes. Since fruit fly populations only appear after the onset of pre-monsoon showers or normal monsoon rains during June and July, early genotypes might have escaped the infestation by that time. In the close relationship between mango trees and fruit flies, the synchronization of high fly pest abundance with fruit maturity is crucial for the mango fruiting season and growers (Vayssieres *et al*. 2009). It is not surprising to observe the highest fly counts during the maturity period, especially for mid-season and late maturing mango genotypes, with these counts also being significantly correlated with the daily rainfall (Vayssieres *et al*. 2014).

Population dynamics and hosts: The data in Table 2 depicts the ripening periods of various host crops surrounding the main mango orchards. Throughout the year, suitable host horticultural crops are available, allowing fruit flies to complete their life cycle in continuity. From May to August period, the primary emergence of *B. dorsalis* was observed in mangoes and other fruits such as guava, papaya, lemon, and cucurbits. During September to October, fruit flies continued their life cycle on the rainy season crop of guava, and from October onwards, they were observed in the majority of fruiting host plants present in the selected orchards. In addition to guava (*Psidium guajava*) sightings in November, fruit flies were primarily found on different citrus species, including mandarin (*Citrus deliciosa*), orange (*Citrus sinensis*), grapefruit (*Citrus paradisi*), pummelo (*Citrus maxima*), and Kinnow mandarin, from November to February. Fruit infestations by the fruit flies were particularly noticeable in March on ber (*Zizyphus* sp.) fruits, and from May onwards, the fly population persisted on a various host plants (fruit and vegetable crops), encompassing 11 fruit species from seven botanical families and vegetables from two families.

The population of fruit flies was higher in the mixed orchard compared to the homogeneous one, likely due to varietal differences and the availability of various hosts with the different fruit maturity time throughout the year. In the mixed orchard, all four species (*B. dorsalis*, *B. zonata*, *B. correcta*, and *B. cucurbitae*) were observed except in the homogeneous orchard, which explains that the absence of *B.*

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* is due to non-availability of host plant species within that particular orchard. Several factors contribute to the observed increase in the abundance and diversity of fruit flies, including abiotic variables as well as biotic variables like host plants (Tan and Serit 1994, Aluja and Mangan 2008, Jayanthi and Verghese 2011, Migani *et al*. 2014, Rasolofoarivao *et al*. 2022). According to the findings of Celedonio-Hurtado *et al.* (1995), the seasonality of fruit flies is frequently associated with host plants that bridge populations during periods when the primary hosts are not accessible. The correlation between fruit availability and fruit fly populations has been observed in other species as well, including the West Indian fruit fly, *Anastrepha obliqua*, the Mexican fruit fly, *Anastrepha ludens* (Aluja *et al*. 1996), and B. dorsalis (Tan and Serit 1994). Therefore, the existence of wild hosts in close proximity to the orchards acts as an additional crucial factor that contributes to these population fluctuations (Vayssieres *et al*. 2009, Badii *et al*. 2015).

Among the species monitored, four tephritid species, which are commonly found in mango orchards and known for infesting mangoes, hold significant economic value among the observed species. The levels of population density experienced a rise following the initial substantial rainfall, highlighting the crucial role of environmental factors in the process of invasion and which reaffirms that rainfall can be utilized as a short-term indicator for predicting fruit fly populations. The abundance of fruit flies is likely to be sustained due to the continuous presence of cultivated horticultural crops and other host plants throughout the year. To ensure effective management of fruit flies, it is necessary to have precise and reliable information regarding the species involved and the range of hosts they infest. Our results suggest that various factors, such as changes in environmental conditions, nutritional composition, defensive chemistry in fruits, and the availability of alternative host plants, may have contributed to the observed patterns. Adjusting the timing of harvest can be a helpful strategy in reducing the likelihood of infestation. However, further research is necessary to better understand these potential mechanisms and develop sustainable management strategies against these economically significant pests.

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