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RESEARCH ARTICLE

Seasonal Dynamics and Morphological Characteristics of Mango Fruit Flies in Different Orchards of Faisalabad

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ABSTRACT

This study examined the morphological traits, seasonal infestation dynamics, and environmental influences of the two main mango pests in Faisalabad, Pakistan, Bactrocera dorsalis and Bactrocera zonata. 400 mango fruits were examined at two orchards between April and July 2024, and the species composition, infestation, and larval development were evaluated. Peak fruit maturity was accompanied by the highest infestation rates, which rose gradually from 5% in April to 65% in July. While morning and afternoon humidity showed high negative relationships (r = −0.873 to −0.839), temperature showed a strong and positive link with both larvae per fruit (r = 0.994) and infested fruits (r = 0.988), according to Pearson correlation analysis. Rainfall had a less pronounced adverse effect (r = -0.366 to -0.235). Infestation was highest in ripe and overripe fruits (14–16%, 5–15 larvae/fruit) and lowest in green fruits (4%, 1-3 larvae/fruit), according to laboratory rearing. Upon species identification, B. zonata outnumbered B. dorsalis (34.5%) by a margin of 64.5%. Clear species separation based on body size, wing venation, and abdomen patterning was validated by morphological examination. According to these results, temperature is the main factor for fruit fly accumulation, and the likelihood of infestation is further increased by fruit maturity. The study offers baseline information that is necessary for creating integrated pest management plans meant to lower yield losses in mango plantations caused by fruit flies.

Key words: *Bactrocera zonata*, *Bactrocera dorsalis*, Mango infestation, Morphological characteristics, Climatic factors, Pearson correlation, Faisalabad

INTRODUCTION

Fruit flies (Diptera: Tephritidae) are highly devastating problem and economically affect agricultural crops. They target and adversely affect the diverse range of fruits (Ismail *et al.*, 2023a). A large group of *Bactrocera* fruit flies (128 recognized species) are distributed in hot and humid areas of Asia, infesting various hosts. Most significantly, 98 species belong to India and Pakistan, of which 48 are known to attack mangoes and other fruits. Fruit fly attacks have made the nutritious and economically valuable mango fruit very vulnerable. The mango season is from March to September, when fruit fly pests are active (Amur *et al.*, 2023). According to the research, losses attributed to tephritid fruit flies in Pakistan have made a substantial jump. A study notably revealed that the Oriental fruit fly (*B. dorsalis*) alone was responsible for 30% of mango fruit production loss (Noman *et al.*, 2021a).

Favorable climatic factors including high temperatures and humidity promote the life cycle and population growth of Tephritidae species, especially *Bactrocera dorsalis* and *B. zonata* making the infestation worse (Rauf *et al.,* 2021a). In addition to causing physical harm, the female fruit fly's piercing of the fruit skin to lay eggs encourages microbial invasion, which causes early fruit drop and spoiling (Momen *et al.,* 2025).

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Furthermore, fruit flies have polyphagous nature allows it to live on a variety of host plants, which makes managing it especially difficult during overlapping fruiting seasons.

Mangifera indica (L.) classified under Anacardiaceae, is among extremely valued fruit crops in the tropics and subtropics. Spanning over 4 thousand years of cultivation history in the Indian subcontinent, mango was Pakistan's national fruit originating in the Indo-Burma region (Nagaraj *et al.,* 2014a). It is known as "Majestic fruit" due to its exceptional taste, flavour, and aroma. Mango is high in antioxidant commercially cultivated in over 87 countries, producing 1.8 million tons of mangoes in Pakistan. Sindh and Punjab are the main production areas. Pakistan nurtures many mango varieties, such as Chounsa, Sindhri, Langra, Anwar Ratool, Dusehri, Fajri, Bangan Pali, Saroli and many others (Ashraf *et al*., 2013; Mukhtar, 2016). Pakistan has five months of mango season: May and September, starting with mangoes from Sindh starting in mid-May and Punjab finishing in late September. Mango production and exports of mango rank among the top 7 countries in the world (Memon *et al.,* 2016). Kazakhstan, the United Arab Emirates (UAE), the United Kingdom (UK), Uzbekistan, Oman, and the European Union (EU) stand out similar to top mango target market in the state.

Pakistan is currently the ranked second in producing of mangoes and has gained popularity in recent years for producing several types of mango fruits. The biggest threats to mangoes in Pakistan are fruit flies, and research from a small quantity of samples and locations indicates that Oriental and peach fruit fly are featured in the nation (Hosni *et al.,* 2011) An essential component of pest management is monitoring fruit fly populations in mangos. In order to guarantee that mango quality meets international regulations, notably those for international shipment, this protocol is necessary (Chaudhary *et al*., 2014).

Reproductive potential serves as a critical parameter linking seasonal dynamics with physical characteristics of fruit flies including egg-laying capacity and the size of their reproductive organ (Scolari *et al*., 2014). Fruit flies have greater reproductive functionality, including larger reproductive organs and more eggs produced (or less spent) than in winter, such as peak mango availability (Jaleel *et al.,* 2018). Therefore, fruit flies can contribute to population growth during the breeding season. In contrast, during unfavorable periods, reproductive activity is known to be reduced. The reproductive organs are also smaller, showing a lesser allocation of energy for reproduction (Amur *et al*., 2017).

This study fills these gaps by conducting a four-month analysis of fruit fly populations in mango orchards. By examining seasonal variations, morphological characteristics, and controlled laboratory rearing, this research will offer new insights into fruit fly dynamics in the region. Hence keeping in view above mention factors, to investigate the seasonal patterns of *Bactrocera dorsalis* and *B. zonata* infestations in mango orchards of Faisalabad, focusing on the relationship between climatic factors and infestation levels. It also examines the morphological characteristics of *B. dorsalis* and *B. zonata*, including body size, wing venation, sexual dimorphism, abdominal markings, and coloration, and then determines the consequences of different mango growth stages on the extent of infestation with larval development.

MATERIALS AND METHODS

Study area

This research was carried out in two mango growing locations within Faisalabad, Punjab, Pakistan. The primary sites for mango collection and infestation assessment were Horticulture Square 9, University of Agriculture Faisalabad (UAF), and the Praveen Shaker Ladies Complex, Faisalabad. These sites were selected due to their established mango cultivation and history of fruit fly infestations. Observations were made over the mango-bearing season from April to July in 2024 corresponding with peak mango maturity and fruit fly activity periods. All the collected data were analyzed at the Dengue Vector Research Laboratory located in the Department of Entomology at UAF.

Collection and rearing of mango fruit flies

Fruit samples were taken from both orchard locations in order to cover a range of cultivation and environmental variables. Sampling was conducted from April to July, three times per month. During each visit, 25-30 damaged mangoes were randomly collected. Targeting both healthy and damaged mangoes, random sampling was done to guarantee that representative infestation data was collected. In order to prevent further contamination or deterioration, the assembled fruits were carefully shipped to the testing facility under carefully monitored conditions. Each batch was labeled with the date and location of the collection.

Mango fruit samples were collected over a four-month period, covering both the off-season (April and May) and the on-season (June and July). During the off-season, fruits were collected in three replications per month, with each replication conducted at regular intervals. Overall, of 200 mango fruits were collected within the off-season. Out of these, 60 larvae (maggots) were extracted. During the on-season (June and July), mango fruits were obtained from two different locations, accompanied by three replications per month. Overall, 200 mango fruits were assembled, out of which 170 fruits were found infested by fruit flies, while 30 fruits were free from infestation. From the infested fruits, approximately 100 larvae were extracted.

Laboratory Rearing of Larvae

To separate the larvae, sterile knives and scalpels were used to cut each mango fruit in the lab. To avoid desiccation, the larvae were carefully moved into petri plates and plastic containers lined with absorbent paper using soft brushes and fine forceps. In order to maintain the proper humidity levels required for larvae life, cotton that had been wet with water was also added to the containers. In order to successfully pupate larvae and emerge adult flies, the containers were maintained in an environmental chamber or a room with controlled circumstances that mirrored the natural field habitat. During the off-season collections, the 60 larvae developed into approximately 30–35 pupae. In the on-season collections, 100 larvae developed into around 80 pupae.

Pupal Development and Adult Emergence

From the pupae collected during the off-season, 20–25 adults successfully emerged and survived. During the on-season, 50 adults emerged and survived from the 80pupae collected. The culture was maintained at 27±2°C temperature and 65%±5% RH with the photoperiod of 12L: 12D.

Species Identification of Adult Fruit Flies

Microscopic examination of the emerged adults revealed that, during both season collections, 64.5% of the adults were identified as *Bactrocera zonata* while 34.5% were identified as *Bactrocera dorsalis.* According to a survey conducted by CABI International, a total of 2,690 *B. dorsalis* as well as 5,114 *B. zonata* individuals documented from Punjab samples. In contrast, in Sindh, 2,693 *B. dorsalis* and 156 *B. zonata* individuals were documented. These findings indicate the dominance of *B. zonata* in Punjab, whereas *B. dorsalis* represented as predominant species in Sindh (Gul *et al.,* 2024).

Morphological description of fruit flies

Adult fruit flies were successfully reared and then examined morphologically. Using a stereomicroscope and photography equipment, differences in body size, wing venation, pigmentation, and abdominal structures were recorded. Oriental fruit fly has a distinct T-formed pattern on the abdomen, a partially black trunk with two golden band, and a body size of 6.5±5.00 mm. Their wings contain dark anal streaks and borders. The male's abdomen is chocolate with dark markings. The sclerite is totally dark. Compared to the female, the male is a little shorter.

The T-shaped pattern is lacking in reference to *B. zonata;* their wings have no dark edges or anal streaks, and their abdomen and trunk are tan with two golden strips that are out of alignment. Their body size is 5.5±5.00mm. The female *Bactrocera zonata* flies have an extended abdomen, whereas the males have a rounded abdomen as shown in Table.

Effects of Fruit flies on different stages of mangoes

Fruit flies significantly impact mangoes at various growth stages, with the severity of infestation varying depending on the fruit's maturity. Young fruits (Green, Green mature and first yellow point stage) experience a relatively low infestation rate of 4%, with an average of 1-3 larvae per fruit. As the fruits ripen, (Second and third yellow point stage) the infestation rate increases to 10-11% and the number of larvae per fruit rises to 3-10 Mature fruits (Ripe and overripe) are the most affected, with an infestation rate of 14-16%and 5-15 larvae per fruit. These findings highlight the need for targeted pest control measures, particularly during the ripening and mature stages, to minimize damage and ensure healthy mango yields.

RESULTS

The seasonal dynamics of infestation by fruit flies were followed from April through July 2024, which covered the period of highest production of mango in the location of the study. During this time interval, the climatic variables of temperature (°C), relative humidity (%) and rainfall (mm) were also registered and together with infestation variables: number of larvae per mango and total fruits collected, and total infested fruits.

Correlation of Climatic Factors with Fly Population

Pearson correlation analysis was used to investigate the association between climatic factors and fruit fly population dynamics. Higher temperatures from April to July created favorable conditions for fruit fly development, reproduction, and infestation intensity, as evidenced by the very strong and highly significant positive correlation between temperature and the number of infested fruits (r = 0.988) as well as the number of larvae per mango (r = 0.994). On the other hand, there were significant negative relationships between infestation parameters and relative humidity in the morning and afternoon. Larvae per mango (r = -0.873) and infested fruits (r = -0.857) showed a negative

Table: Morphometric Measurements of *Bactrocera dorsalis* and *Bactrocera zonata*

Characteristic	Measurement	*Bactrocera zonata*		*Bactrocera drosalis*	
		Male	Female	Male	Female
Body Size	length (mm)	5.0-5.5	5.5-6.0	6.0-6.5	6.5-7.0
	width (mm)	1.12±0.05	1.12±0.05	3mm	3mm
Wing Venation	Dark band	reduced	reduced	completely marked	completely marked
	Dark anal streak	Absent	absent	present	present
	Wing cell hairs	Absent	Absent	present	present
Thorax coloration	T shaped pattern	without	without T	with T	with T
	partly black	absent	absent	present	present
	completely brown	present	present	absent	absent

correlation with morning humidity, although afternoon humidity showed similar patterns (r = -0.832 for larvae per mango; r = -0.839 for infested fruits). According to these findings, fruit fly activity and larval development are generally suppressed by higher humidity levels, but a significant increase in infection was observed in later months, coinciding with decreased humidity levels. In comparison to temperature and humidity, rainfall showed less of an impact on fly abundance, showing smaller negative relationships with larvae per mango (r = −0.366) and infested fruits (r = −0.235).

These associations were further supported by a seasonal examination of infestation rates. Data on monthly infestations showed a consistent increase from 5% in April to 65% in July, indicating that fruit fly pressure increased gradually as mango fruits became older and temperatures increased. Infestation rates increased significantly from 40% in the off-season to 85% in the on-season when comparing the off-season (April–May) and on-season (June–July) periods. On the other hand, the percentage of mangoes that were not infested fell precipitously from 60% in the off-season to 15% in the on-season. All of these results shown in [Figure 1] that temperature is the most important climatic element influencing the growth of fruit fly populations, whereas excessive humidity and, to a lesser extent, rainfall serve as suppressors.

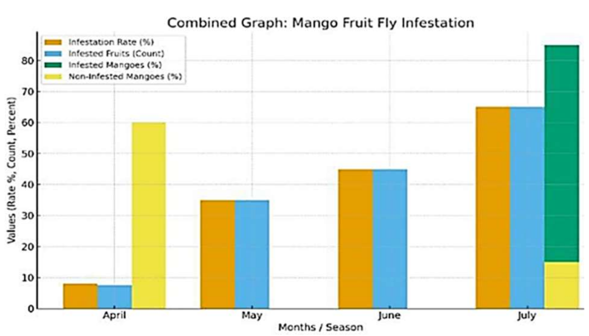

Fig. 1: shows infestation rate, infested fruit counts, and the seasonal trend of infested vs. non-infested mangoes.

Morphological Characteristics of Fruit Flies

Analysis of variance (ANOVA) and Least Significant Difference (LSD) tests were used to determine the mean separation of the morphological characteristics of *Bactrocera zonata* and *Bactrocera dorsalis* throughout seasons. The findings showed that while season (F = 17.86, p = 0.024) and species (F = 162.61, p = 0.001) had a substantial impact on body length, their interaction was not significant (p > 0.05). LSD comparisons revealed that *B. dorsalis* (6.62 mm) was substantially larger than *B. zonata* (5.74 mm), with the maximum length observed in off-season *B. zonata* (6.75 mm), and that on-season flies (6.33 mm) were considerably longer than off-season flies (6.04 mm). ANOVA showed a marginal influence of species (F = 9.63, p = 0.053) and no significant effects of season (p = 0.405) or interaction (p = 0.364) on male wing expanse. Although *B. dorsalis* (12.65 mm) tended to have larger wings than *B. zonata* (11.88 mm), the LSD results showed that all groups were in the same homogenous category, indicating that male wing expanse remained statistically consistent between treatments. With LSD comparisons revealing overlapping homogenous groups, female wing expanse showed a significant seasonal impact (F = 7.48, p = 0.072) but no species or interaction differences; on-season females (12.53 mm) had somewhat larger wings than off-season females (12.40 mm). On the other hand, there was no significant interaction between the season (F = 13.78, p = 0.034) and species (F = 211.56, p = 0.001) and female weight. *B. dorsalis* (12.28 mg) was significantly heavier than *B. zonata* (10.36 mg), and the heaviest group was on-season *B. dorsalis* (12.6 mg). LSD also showed that on-season females (11.56 mg) were heavier than off-season ones (11.07 mg). The male weight of *B. dorsalis* (12.65 mg) was substantially heavier than that of *B. zonata* (11.88 mg), indicating a highly significant species effect (F = 40.79, p = 0.008) but no seasonal or interaction effects. Body length and weight increased gradually between April and July, according to monthly observations for all parameters, with *B. dorsalis* continuously exceeding *B. zonata* in [Figure 2]. Together, these statistical findings suggest that species identity and seasonal conditions dominate morphological traits, with *B. dorsalis* exhibiting noticeably better development parameters, potentially increasing its ecological fitness and economic effect in mango orchards.

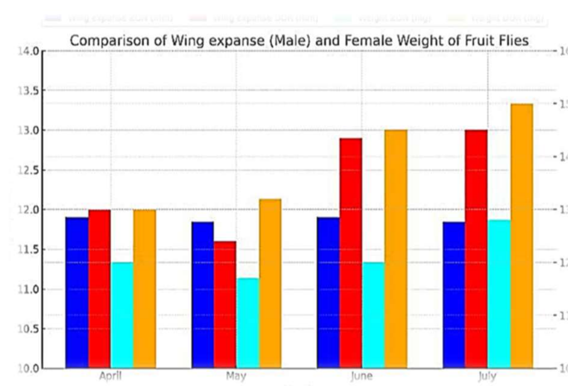

Fig. 2: Comparison of wing expanse and weight of *B. zonata* and *B. dorsalis.*

Impact of Mango Growth Stages on Infestation and Larval Development

Infestation Rates at Different Mango Growth Stages

The infestation rates of fruit flies varied significantly across different mango growth stages, highlighting the vulnerability of fruits at various maturation points (Figure 4.9). The study categorized mangoes into three main growth stages: young fruit (green, green mature, and first point yellow stage), ripening fruits (second and third yellow point stage), and mature fruits (ripe and overripe).

The least fruit infestation was recorded in young fruits, with approximately 4% and 1 to 3 larvae per fruit. The infestation rate was higher in ripened fruit, ranged between 10 to 11%, with the increasing number of larvae per fruit ranged from 3 to10 larvae. Fruits at maturity were the most infested, from 14 to 16% of infested fruits and larvae number increased from 5 to 15 per fruit as shown in [Figure 3]. This pattern suggests that as the mangoes ripen the infestation by the fruit flies and the larval development increase possibly as the result of changes in the fruit chemistry, texture and access to the fruit.

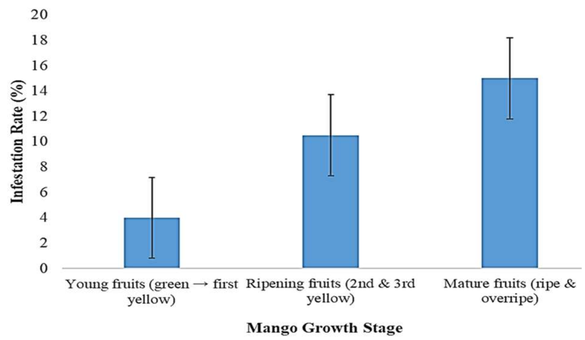

Fig. 3: Fruit Fly Infestation at Different Mango Growth Stages.

Species Identification and Proportions

Species Distribution from Lab Rearing

Laboratory rearing of larvae collected from mango orchards enabled the identification of adult fruit flies at the species level. Out of the total adults emerged, *Bactrocera zonata* was identified as the predominant species, accounting for 65.5% of the population [Figure 4], while *Bactrocera dorsalis* made up 34.5%. This indicates a higher infestation pressure from *B. zonata* in the sampled areas.

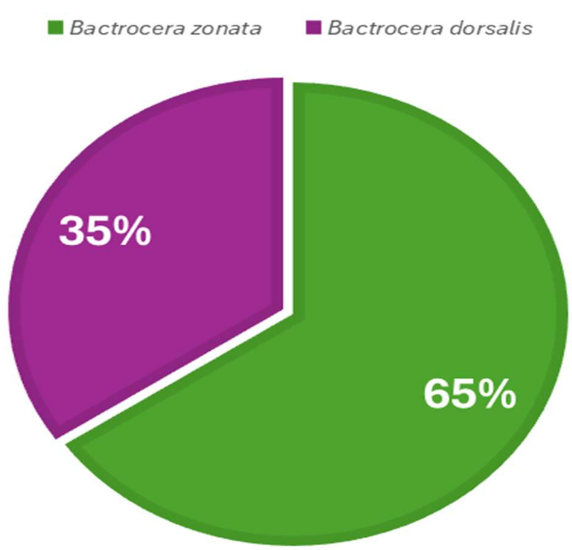

Fig. 4: Species proportion of adult fruit flies identified from lab rearing.

DISCUSSION

The study's results reveal a significant increase in fruit fly infestation rates from the off-season (April–May) to the on-season (June–July), consistent with the general pattern observed in fruit fly ecology studies. Infestation rates escalated from 8% in April to 65% in July, with larvae per fruit rising accordingly. This seasonal dynamic is similar to the results of Winkler *et al.* (2020) and Yu *et al.* (2022), who pointed out that temperature and humidity changes are the main environmental factors of population increase of fruit flies. It was observed that there was a high significant positive correlation between temperature and infestation intensity (r = 0.994) and otherwise for the humidity. This supports findings of Momen *et al.* (2025) who indicated that the Bactrocera species do best under warm, moderately dry conditions that are associated with increased reproduction and larval development. The low association between infestation and rainfall implies that although rainfall affects larval microhabitats, it is not the main factor in this semi-arid mango-growing area, similar to those observed by Mafirakurewa (2016). Such climatic influences emphasize the importance of seasonal forecasting for IPM. As suggested by Dias *et al.* (2018), we suggest the focus of control and monitoring be placed on warmer months where the reproductive success of fruit flies is at its highest. Not changing management approaches according to the seasonal phenology of the pest can lead to significant yield loss since the fruit fly population increases quickly under favorable conditions. The data clearly demonstrate that the stage of mango fruit growth strongly influences fruit fly infestation rates and larval development success. Infestations were much higher (14–16% fruit infested, and 5–15 larvae per fruit) in mature versus young and ripening fruits. This tendency would be in accordance with the observed by Marsden (2014) that when the fruit are mature, they are more susceptible, the fruit chemistry and texture changes and this may allow to the mature fruits more attractive and easier for oviposition.

In addition, larval development success, pupation, and adult emergence were significantly higher in late-stage fruit, meaning that these stages support more suitable environments for that larval survival and development. These findings were consistent with those of Morimoto *et al.* (2020) who suggested that the physical softness and higher sugar content in mature fruits create an optimal microenvironment for larvae. This highlights the importance for pest management strategies that are based on the Phenology of the attacked plant fruit in order to optimize the efficacy of the control. Although the tendency is evident, it should be underscored that some variation about this trend is to be expected as a result of other factors (orchard microclimate, occurrence of natural enemies) which were not directly recorded in our study but were emphasized by Vargas *et al.* (2015) as key to larval mortality rates. Thus, management interventions targeting periods of peak fruit maturity may prove more effective, reducing both larval survival and subsequent adult emergence, ultimately lowering population build-up. This targeted approach is advocated by Dias *et al.* (2018) for sustainable fruit fly control. The predominance of *Bactrocera zonata* in the sampled mango orchards, comprising approximately 65% of the adult population, aligns with reports by Raza *et al*. (2023) and Mahmoud *et al*. (2020), who noted *B. zonata*'s widespread distribution and competitive advantage in South Asian mango ecosystems. Then, similar to findings by Mahmoud *et al.* (2020). Morphometric analyses revealed that *B. dorsalis* individuals are consistently larger than *B. zonata* in body length, wing expanse, and weight, confirming patterns observed by Vargas *et al.* (2015). Sexual dimorphism was apparent, with females larger than males in both species, consistent with reproductive biology where female size correlates with fecundity (Aluja and Mangan, 2012). These variations in size and shape have presumably ecological consequences on, for example, dispersal and competitive ability. Body length and female weight showed a significant aspect of the seasonal morphological variation, it increased during the on-season, denoting phenotypic plasticity in response to environmental conditions and resource availability (Vargas *et al*., 2015). However, measures such as male wingspan were consistent, perhaps the result of the limitations of flight mechanics and mating activity (Makumbe *et al*., 2020). The morphological differences and their phenological variation emphasize the potential roles of phenology and species in pest management. Larger-sized *B. dorsalis* individuals with higher flying capacity may contribute to gene flow and invasion of new territories, and *B. zonata* higher prevalence reinforces its predominant role in what regards to local infestations. The data of this study are helpful in developing the suitable integrated pest management (IPM) for *Bactrocera zonata* and *Bactrocera dorsalis* in mango orchards. The strong seasonality in both infestation intensity and larval development demeanour suggests that management should be targeted within on-season months (June–July), when fruit fly populations are at maximum and inflict the most damage. This is consistent with the findings of Ekesi and Billah (2007) that interventions should be executed at certain period when the pest's life is vulnerable. The predominance of *B. zonata* highlights the need to target control (e.g., including baiting and trapping) at this species, though the presence of *B. dorsalis* indicates that a simultaneous approach that takes co-occurrence into account and prepared for possible changes in population dynamics is necessary (Motswagole, 2017; Motswagole *et al*., 2019). Variation in morphology along with the patterns of seasonal growth suggest that larger, more robust adults of *B. dorsalis* might be capable of greater dispersal, and thus landscape-level, rather than orchard-specific, management may be warranted. In addition, higher proportion of infestation and larval survival in ripe fruits, emphasize the need for tracking fruit phenology to deploy control measures early. Practices such as sanitation (infested fruits removed), biological control agents use, and chemical control precisely timed to fruit maturity stages can optimize efficacy, while reducing the reliance on broad-spectrum insecticides and the associated environmental impact (Vargas *et al*., 2015).

Conclusion

This study examines the economic and nutritional importance of mango cultivation in Pakistan, emphasizing challenges from the mango fruit fly, mainly *Bactrocera zonata* and *Bactrocera dorsalis*, which cause significant crop losses. Experiment was conducted in Faisalabad from April to July 2024, the research analyzed morphology and population dynamics, revealing peak infection rates of 4% to 16% in June, with contamination reaching up to 50% of fruits. Findings highlighted temperature (optimal at 33°C) and humidity (below 40% increases infestation) as critical factors in infestation dynamics. The study advocates for tailored integrated pest management (IPM) strategies aligned with local environmental conditions, recommending seasonal pest control interventions during peak months. It also stresses the utility of morphological differences for targeted pest management, suggesting that adaptive and sustainable practices could significantly enhance mango production while reducing reliance on chemical pesticides. So, the finding indicated the evidence in support of nuanced IPM approach involving seasonal monitoring, species-level targeting, and phenology-based control options to manage fruit flies sustainably in mango production landscapes.

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Data Availability: The data will be available upon request to the corresponding authors.

Ethics Statement: All animal studies have been approved by the relevant ethics committee or institutional supervisory board and have been conducted in accordance with the ethical standards.

Author's Contribution: Misbah Batool contributed to the study design and manuscript drafting. Tahseen Javaid provided methodology support and assisted with data analysis. Waseem Akram offered technical guidance and contributed to species identification. Ateeb ur Rehman performed statistical analysis and prepared the figures. Roshana Nawaz assisted with field work and laboratory processing. Samia Sarfraz contributed to the literature review and data organization.

Generative AI Statement: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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