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REVIEW ARTICLE

Advanced approaches for managing ber fruit fly (*Carpomyia vesuviana* Costa) in Indian jujube (*Ziziphus mauritiana* Lamk.) orchards

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Abstract

Jujube or Ber, a prominent fruit of arid zones, is heavily infested by fruit flies, primarily *Carpomyia vesuviana* Costa and *C. incompleta* Becker (Diptera; Tephritidae). These monophagous pests significantly reduce ber fruit yield and quality, with potential losses of up to 80% under severe infestations. The intensity of damage increases as the season progresses. In addition to *Carpomyia* species, jujube fruits are also attacked by fruit flies such as *Bactrocera dorsalis* (Hendel), *B. correcta* (Bezzi) and *B. zonata* (Saunders). This review focuses on the lesser-studied characteristics of *Carpomyia* species, particularly the key elements of taxonomic identification based on molecular and morphometric traits, as abundant literature is available on *Bactrocera* species. Furthermore, the review discusses the nature and extent of damage, seasonal incidence, the influence of environmental factors on population dynamics and resistance mechanisms. Managing fruit flies in the ber ecosystem is challenging due to the complex of species involved, but can be addressed through integrated approaches that include management, resistance mechanisms and biological control.

Keywords

ber; *Carpomyia vesuviana*; *C. incompleta*; ecology; integrated pest management; *Ziziphus* spp.

Introduction

Ber or Jujube (*Ziziphus spp.*), originates from the Indian subcontinent, Indo-Malaysia region or South and Southeast Asia (1, 2) and has been cultivated for its nutritious and palatable fruits for thousands of years (3). The fruits are consumed fresh, dried, or processed into products like jam, jelly, bread and cake. They are rich in polysaccharides, phenolics, flavonoids and saponins and are known for their medicinal properties, including treating palpitations, insomnia, anemia, splenic insufficiency, diarrhea, hepatotoxicity and fever. There are approximately 170 species within the genus Ziziphus (4), with 17 native to India (5). The global distribution of ber is shown in Fig 1. Z. jujuba

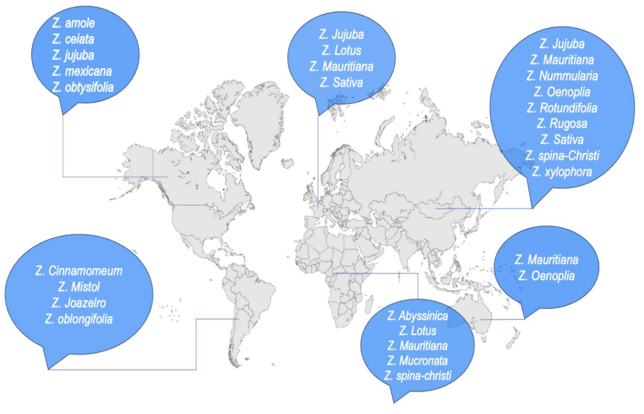

Fig. 1. Global distribution of *Ziziphus spp.*

(*Chinese jujube*) and *Z. mauritiana* Lamk. (Indian jujube or ber) are the two main cultivated species found across diverse climates. It grows wild in southern Rajasthan and is widely cultivated in states like Gujarat, Maharashtra, Haryana, Punjab, Rajasthan, Tamil Nadu, Andhra Pradesh, Karnataka, Bihar, Chhattisgarh, Madhya Pradesh, Assam and West Bengal.

Balikai (5) reported twenty-two insect and non-insect pests infesting Ziziphus (ber) in Karnataka State. Similarly, 23 species of pests were reported in ber in Andhra Pradesh (6). Jujube (ber) fruits are also infested by fruit flies, *Bactrocera dorsalis* (Hendel) and *B. zonata* (Saunders) (75). In Punjab, 37 insect pests infest ber. The primary pests include fruit fly (*Carpomya vesuviana* Costa), *Bactrocera dorsalis* (Hendel), *B. zonata* (Saunders), ber butterfly (*Tarucus theophrastus* Fabricius), fruit borer (*Cadra cautella* Walker), bark-eating caterpillar (*Indarbela tetraonis* Moore), white grub (*Holotrichia consanguinea* Blanch), and stone weevil (*Aubeus himalayanus* Voss) (7, 8, 9). Ber fruit flies, belonging to the family *Tephritidae*, comprise over 4,000 species. The subfamily Trypetinae is divided into seven tribes, one of which is Carpomyini, consisting of 123 species in 12 genera. The genus *Carpomya* includes species such as *C. incompleta* (Becker 1903), *C. liat* (Freidberg 2016), *C. pardalina* (Bigot 1891), *C. schineri* (Loew 1856), *C. vesuviana* (Costa 1854) and *C. wiedemanni* (*Goniglossum wiedemanni* Meigen 1826).Ber cultivation is under threat from the fruit fly complex, which can cause yield losses of up to 80% in severe cases (10). It infests various ber species, including *Z. mauritiana*, *Z. jujube*, *Z. ziziphus*, *Z. sativa*, *Z. nummularia* and *Z. rotundifolia* (11-21) (56)(70). Many farmers rely on insecticides for managing *Bactrocera* fruit flies. However, effective management requires combining conventional methods like collecting fallen fruits, raking the soil around tree trunks, monitoring and mass trapping with pheromone traps for *B. correcta*, *B. zonata* and *B. dorsalis*. The use of new molecular insecticides during the pea stage and botanicals during fruit maturity is also essential. Innovative approaches, such as identifying attractants from fruit volatiles, developing synthetic pheromone lures and inducing resistance through silica-based sources, are being explored for better management of the *Bactrocera* fruit fly complex.

Infestation of fruit flies and their distribution

The Ber crop is infested by two species of *Carpomyia*: *C. incompleta* and *C. vesuviana* (22). The infestation of jujube plants by *C. incompleta* has been observed in various regions across Europe (France, Italy and Romania), Asia (Iran, Oman, Saudi Arabia, Iraq, UAE and Yemen) and Africa (Egypt, Eritrea, Ethiopia, Libya, Niger, Senegal, Sudan and Morocco). Meanwhile, *C. vesuviana* has been recorded in India, Georgia, Oman, Turkmenistan, Uzbekistan, Tajikistan, Mauritius, Europe, Indian Ocean Islands, Turkey, Cambodia, Cyprus, Iran, Iraq, Lebanon, Thailand, Syria, Ukraine, Russia, Azerbaijan, Afghanistan and China (23, 24) (Fig 2). The study employed gridded resolution datasets from the CLIMEX model for CliMond 300 for the periods 1987-2016 and 2071-2100, showing that the distribution area of the Ber fruit fly (*C. vesuviana*) increased from 50.95% to 61.59% globally. The distribution of *C. vesuviana* across various states of India is detailed in Table 1.

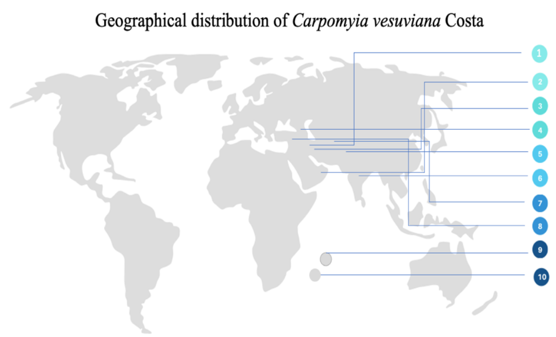

Fig.2. Geographical distribution of *C. vesuviana* Costa (1- Iran, 2- Oman, 3- Iraq, 4- Georgia, 5- Uzbekistan, 6- India, 7- Turkmenia, 8- Turkey, 9- Indian ocean island (Rodrigeus, Seychellus), 10- Mauritius

Table 1. Distribution of *C. vesuviana* in India.

Distribution of *C. vesuviana* in India	Reference
Madras, Punjab, Jobner, Aruppukottai, Rahuri, S. K. Nagar	(25)(26)
Haryana	(27)
Rajasthan	(16)(28)(29)
Gujarat	(30)(18)(15)
Tamil Nadu	(31)
Karnataka	(32)(33)(5)
Andhra Pradesh	(34, 35)
Uttar Pradesh	(36)
New Delhi	(37)

Molecular characterization

DNA barcoding has been recognized as an efficient and accurate tool for species identification (38, 39). Jia et al. (40) sequenced the entire mitogenome of *Bactrocera* fruit fly (BFF) species within the subfamily Trypetinae. The circular genome, consisting of 15,267 bp, contained a standard set of genes: two ribosomal RNA subunits (large and small), 22 transfer RNA genes, 13 mitochondrial protein-coding genes and a non-coding A+T-rich control region. Phylogenetic analysis revealed that Trypetinae BFF forms a distinct monophyletic group, clearly separated from the Dacinae and Tephritinae subfamilies, with maximum support (p = 1). This study contributes to our understanding of phylogenetics, population genetics and species identification. *Ceratitis incompleta* was identified molecularly using DNA barcoding. A 709 bp fragment of the mitochondrial cytochrome c oxidase subunit I (COI) gene was successfully amplified using specific primers. The nucleotide sequence ranged between 637 and 644 bp for adults and larvae, showing no significant variation. The sequence displayed 99.84% identity with *C. incompleta* and 94.8-95.2% identity with *C. vesuviana* (41). Taher & Alyousuf (42) also used the mitochondrial COI-COII marker to identify fruit flies. Their PCR product was 710 bp and the phylogenetic analysis showed two distinct groups. The first group contained two clusters, *C. vesuviana* and *C. incompleta*, from the eastern and southeastern parts of the world. The second group, *C. schineri*, originated from the western region.

Life History of *C. vesuviana*

Eggs

The female laid spindle-shaped, creamy white eggs just beneath the fruit's surface, with pre-oviposition lasting 2-12 days, oviposition 3-44 days and post-oviposition 0-14 days. Mating and egg-laying occurred during daylight (17), with females favouring the central distal area of the fruit (45). Around 72% of eggs were laid within 3-7 days, peaking in November and February. Each female laid an average of 19.1 eggs, resulting in 1-4 ovipunctures per fruit.

Maggot

Maggots bored into ripened fruits to feed on the pulp, with pupation occurring after 1.8 to 5 hours. The larval stage lasted 9 to 12 days, while the pupal stage took about 2 weeks (26). Larvae entered the ground for pupation after 3 to 4 hours, with puparia found 5 to 7.5 cm deep, often overwintering in the soil around tree trunks, though sometimes within infested fruits (19). Depending on environmental factors, the pupal period ranged from 14 to 300 days.

Biometrics of fruit fly, *C. incompleta*

Egg

This species has two generations per year: a summer generation lasting 20-35 days and a winter-spring generation lasting 300-330 days. Adults live for 10-20 days. Eggs (1-4 per fruit) are laid on the fruit's outer epidermis and larvae tunnel into the pulp, feeding on the kernel before returning to the pulp. Fully fed larvae pupate in the fruit, especially if it is still unripe when it falls.

Larva

Larvae initially appear translucent white, quickly turning milky. The three larval instars had average morphometric lengths and widths of 3.23 and 0.74 mm, 5.3 and 1.42 mm and 8.7 and 1.96 mm, respectively

Adults

They were small, yellowish and streamlined, with compressed bodies. Females measured an average of 4.91 mm in length, while males averaged 4.11 mm. The wings had a small costal bristle on the front edge and the abdomen was bordered with coarse hairs. The ovipositor measured about 0.63 mm in length and 0.131 mm in width (42).

Nature and magnitude of damage

The female fruit flies lay their eggs in the immature stage of fruits. When the maggots hatch and begin feeding on the pulp, they create galleries filled with excreta, which causes the fruit to rot and taste bitter (19). Infested fruits swell and exhibit oversized developmental retardation; in extreme cases, they may even fall off (7, 46, 47). According to references (15) and (16), the occurrence of *C. vesuviana* severely reduces yield by 13% to 20% and 90% to 100%, respectively. A roving survey conducted across various districts of Haryana recorded a 15% to 20% infestation rate in the Umran variety during 2012. The incidence began in the 46th standard week and gradually increased with the maturation of the fruit in Bawal. In Sardar Krushi Nagar (SK Nagar), the incidence was first observed during the first two weeks of January, reaching 37.50%, before gradually decreasing to 26.00% by the first fortnight of February in the Gola cultivar of Ber. During the second fortnight of December 2018 at SK Nagar, fruit fly infestation in Ber was recorded at 19.2%. This pest caused infestations ranging from 4.0% to 40.0% across different districts of South West Haryana on Ber during 2018, while in SK Nagar, the infestation rates ranged from 5.0% to 35.0%. In 2020, infestation levels varied from 8.0% to 44.0% in several regions of Haryana. In 2022, damage to jujube was recorded at 10% during the second fortnight of December and 12.4% and 5.6% during the first and second fortnights of January 2023, respectively, at SK Nagar, India.

Seasonal Incidence of Ber fruit fly in India

Northern states of India

In Northern India, damage from fruit flies occurs between mid-November and the end of April, with a peak in activity during fruit maturation. According to reference (26), there may be 2 to 3 generations per year. Lakra and Singh (44) reported that there can be 6 to 9 overlapping generations annually. The incidence of damage was highest in December and lowest in March. Additionally, findings from reference (18) indicated that the pupal resting stage occurs in the ground from April to August, leading to damage during the off-season for fruits in Punjab. The eggs deposited in September exhibited the shortest generation time of 23 days (45). In Haryana, damage to *Ziziphus nummularia* fruits from fruit flies during the off-season (June to September) and the harvest season (September to December) ranged from 5.9% to 51.0%, with an average yield loss of 31.2% (56). For *Ziziphus mauritiana*, damage intensity varied from 5.1% to 60.5% during the growing season and from 6.7% to 58.6% during the off-season (June to October). Average losses in individual orchards throughout both the crop season and the off-season were 10.5% to 39.8% and 22.3% to 33.6%, respectively, as shown in Fig. 3.

Central parts of India

Infestation begins in the middle of October in central India, particularly in Gujarat. It intensifies dramatically in the middle of November and lasts until December (15).

Southern parts of India

According to (33) *C. vesuviana* was most active in *Z. mauritiana* in Bijapur. In Karnataka, damages occurred during 2nd fortnight of December to February and in Tamil Nadu infestation happened during 2nd week of November to the end of March.

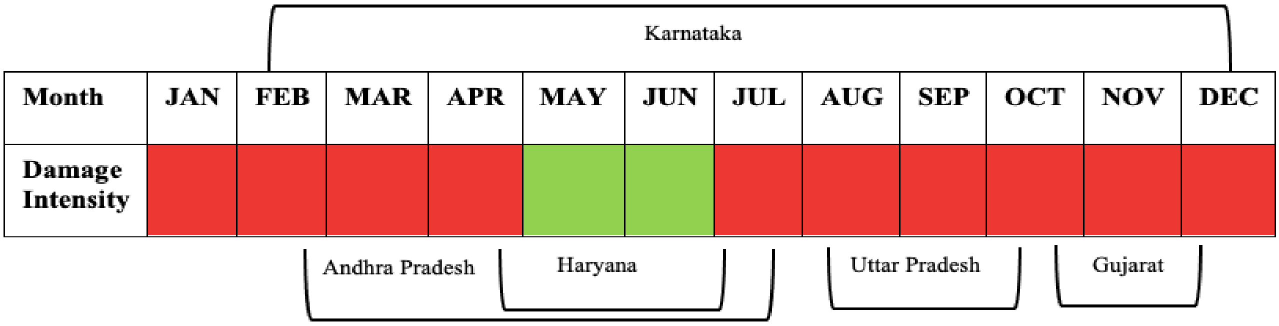

Fig. 3. Seasonal activity of *C. vesuviana* in India

Environment factors and their influence on life table and fruit fly damage

According to reference (45), the ideal temperature for pupal development of *Ceratitis capitata* was 30°C, resulting in a high percentage of adult emergence (74%) and a short pupal period of 15.65 days. The optimal pupation depth for adult emergence was found to be between 3-6 cm. Temperatures of 10°C, 16°C and 40°C would prevent adult emergence for about 50 days (43). Additionally, temperatures above 40°C combined with relative humidity levels below 20-30% were found to be unfavourable for maggot growth and development. Prolonged immaturity stages also occurred at temperatures below 5°C. Fly activity was triggered by sporadic light rainfall (20 to 40 mm per week) occurring from July to August, while it was reduced by rainfall amounts ranging from 50 to 120 mm (45). Findings from reference (27) revealed that the incidence of *C. capitata* was highest at relative humidity levels between 62% and 85% and at temperatures ranging from 17°C to 25.5°C, with minimal incidence observed at 2.3°C and 4.8°C. Reference (33,34) indicated a significant correlation between pest incidence and temperature, but a negative correlation with relative humidity, wind speed and cloud cover. Regarding the presence of fruit flies, a significant negative relationship was found with morning relative humidity, while a positive correlation was noted with evening relative humidity. Reference (48) demonstrated a positive correlation between the occurrence of *C. capitata* and daylight hours, wind velocity and rainfall. Singh (2008) (7) found that *C. vesuviana* pupae could die when the soil was heated by summer irrigation. A study conducted in the Anantapuramu district of Andhra Pradesh over 16 years (2003 to 2018) revealed that the incidence of *C. vesuviana* was observed from the first fortnight of September to the first fortnight of October, with intensity increasing as the season progressed. The study exhibited a negative significant correlation with maximum and minimum temperatures and precipitation, while it showed a positive significant correlation with relative humidity. The incremental increase in incidence followed a linear pattern from September to December.

Mechanism of Resistance

Biophysical traits

Solid pulp textures and smooth or ridged fruit surfaces were linked to the resistant germplasm accessions of Illaichi, Katha and Tikadi. According to Yadav et al. (49), fruit damage percentage has a substantial negative correlation with pericarp thickness (-0.85), pulp-to-stone ratio and fruit length (0.47 and 0.42). Yadav et al. (50) also stated that the physical attributes of fruits vary depending on the fruit type and include dimensions, weight, texture, pulp ratio, color and hardness. The fruits measured 5.0 × 3.9 cm for Banarasiand 2.3 × 2.4 cm for Illaichi, indicating differences in size. They also differed in weight: Illaichi weighed 7.9 g, while Umran weighed 31.5 g. The firmness ratio ranged from 11.21 kg/cm^2 for Thornless to 5.72 kg/cm^2 for Akrota, whereas the pulp ratio varied from 31.1 g (for Kaithali) to 11.4 g (for Reshmi). Cultivars with round and oblong fruit morphologies, such as Bahadurgarhia, Dandan, Gola, Kaithali, Kakrola Gola, Laddu, Safeda Rohtak, Seo Bahadurgarh and Sua, were classified as susceptible. In contrast, the rates of infestation were comparatively lower in cultivars with oblate fruits, such as Illaichi, Illaichi Jhajjar, Katha Bombay and Katha Gurgaon. Additionally, the incidence of infestation was higher in delicate, light yellow and golden yellow fruits (50).

Biochemical basis of resistance

In both resistant and susceptible cultivars, the levels of flavonoids, tannins and phenols were measured on a dry weight basis, ranging from 40.7 to 179.0 mg/100g, 264.8 to 511.6 mg/100g and 113.1 to 239.0 mg/100g, respectively. Among the cultivars, Safeda exhibited the highest flavonoid content at 179.0 mg/100g, followed closely by Tikadi at 176.5 mg/100g, while Chhuhara had the lowest at 40.7 mg/100g. In terms of tannin content, Safeda again led with 511.6 mg/100g, followed by Tikadi at 502.8 mg/100g and Chhuhara at 264.8 mg/100g. For phenol content, Sanaur-4 recorded the lowest at 113.0 mg/100g, whereas Safeda had the highest at 239.0 mg/100g, with Tikadi following at 232.0 mg/100g (51). Generally, phenol content tends to be higher in resistant cultivars and lower in susceptible ones. According to reference (50), Gola had the highest Total Soluble Solids (TSS) content at 20.8°Brix, while Govindgarh Selection had the lowest at 14.1°Brix. Sanaur-3 exhibited the highest acidity at 0.62%, in contrast to Kaithali, which had the lowest acidity at 0.21%. Notably, Kaithali also contained the highest level of vitamin C at 123.35 mg/100g, while Tasbtso had the lowest at 52.03 mg/100g. In terms of total phenolic content, Tasbtso ranked highest at 147.41 mg/100g, whereas Nazuk had the lowest at 84.93 mg/100g.

Biochemical content in Ber

The phenol content in jujube fruits was 260 mg GAE/ 100g DW. Phosphorus was 722.67 and 453.74mg/Kg in fruits and seeds; Ca was 1261.02 and 2228.24mg/Kg. K was 7351.61 mg/Kg in fruits of jujube (76). Zn content was 2.18 - 1.89mg/ Kg in ber fruits (77).

Liu *et al.,* (2022) (78) conducted an experiment on different stages of jujube fruits *viz.,* S1 (Immatured), S2 (Semi ripened) and S3 (Ripened) stages. The total phenols (LC-MS/MS) were in the range of 315.68mg/100g in S1, 156.47 mg/100g in S2 and 109.76 mg/100g in S3 stages.

Integrated Management

Prophylactic measures

Raking and ploughing around the tree trunk

The main cause of infestation is the surviving pupae, which are present in the area around the tree trunk due (52). By subjecting hibernating pupae to sunlight and birds will pick off the pupa, the soil cultivation practices of orchards during the spring (53), summer (54) and rainy season (55) destroy the pupae, resulting in a meaningful decrease in infestation (Table 2).

Clean cultivation

Field cleanliness is a crucial preventive measure that should be consistently practiced to effectively interrupt the reproduction cycle, reduce population growth and prevent infestation. To deter the emergence of fruit flies, it is recommended to collect all fallen, bird-damaged and damaged fruits at regular intervals of two weeks, starting from the time of fruit initiation and continuing through the off-season. Additionally, it has been suggested that reducing fruit fly infestation in an orchard can be achieved by burning all pruned parts of both varietal and wild cultivars of jujube.

Collection and destruction of off-season fruits

Wild species start early fruit set and off-season fruit production serves as a connection to breed and transition to crop. According to (45) destroying off-season fruits aids in lowering fruit fly infection (Table 2).

Harvesting of mature fruits before colour change

Due to bird attacks on immature and semi-ripe fruits, the population of Tephritids increased initially, resulting in large losses throughout the later phases of the crop. Harvesting mature fruits before the colour transition from green to yellow helped prevent such damage (47,57). Additionally, early harvesting at the colour change stage reduced the risk of over-ripening on the trees, which in turn lowered fruit fly survival (43).

Resistant Cultivars

Mann and Bindra (58) recorded that fruit fly damage was lowest in the germplasm varieties Sanaur-1, Safeda Selected, Illaichi, Mircha, ZG-3 and Umran. Tikadi was found to be resistant, while Illaichi was moderately resistant (29). According to (59), the varieties Umran, Tas Bataso, Deshi Alwar and Kishmis were either moderately resistant (21-30%) or highly resistant (11-20%). Tikadi and Illaichi exhibited extreme resistance (up to 10%). Reportedly, Sanaur-2, Umran and Sanaur-6 had the highest levels of infestation, while Illaichi had the lowest levels (60). Resistant lines included B.S.75-3 and B.S.75-1 (61). The cultivars Tikadi, Katha and Illaichi were identified as resistant, whereas BS-75-1, Safeda, Dandan, Gola, Goma Kirthi, Jogia, Narma, Mundia, Reshmi, Seb, ZG-3, Umran and Akharota were classified as moderately resistant. Banarasi Karaka, Banarasi Pawandi, Chhuhara, Kaithali, Thar Sevika and Thar Bhubraj were classified as susceptible, while Sanaur-3, Sanaur-4 and Sanaur-5 were found to be highly susceptible to BFF (62). Results from (63) showed that the variety Umran was resistant to BFF. The variety Kaithali suffered the most fruit fly damage (51.06%), followed by Gola (49.06%) and Dandan (42.07%). The germplasm BS-1 recorded the lowest fruit fly damage (1.51%) and was classified as resistant, while Illaichi (10.63%) and BS-2 (13.37%) were classified as moderately resistant (50). In Bawal, 35 ber entries were evaluated against fruit fly, with less than 1% damage observed in the BS-1 cultivar (Anonymous 2020). At SK Nagar, four ber varieties-Seo, Sukavani, Bhavnagari and Surti Kantha-were found to be free from fruit fly infestation (Table 2).

Pheromones

Li et al. (64) isolated volatile compounds from *C. vesuviana* adults collected from ber fruit using Solid Phase Micro Extraction (SPME) and Gas Chromatography-Mass Spectrometry (GC-MS). They found that male adults released nonanal, while five additional compounds-caryophyllene, chamigrene, camphene, (Z)-3-hexen-1-ol acetate and ocimene -were detected in the fruits. The study revealed that (Z)-3-hexen-1-ol acetate was the most abundant volatile compound, constituting 42.29% of the fruit-derived volatiles. Electroantennogram (EAG) analysis demonstrated that the BFF responded to six compounds, with two new pheromones, geranyl acetate and α-farnesene, identified from other tephritid species, eliciting responses ranging from 0.50 mV to 1.26 mV. In July 2020, adults of *C. incompleta* were collected using Mediterranean fruit fly pheromone traps (Econex S.L., Murcia, Spain) from a six-year-old organic jujube orchard located in Ecija, Seville (Table 2).

Biocontrol Agents

Saxena and Rawat (69) (1968) reported that *Bracon fletcheri*, *Opius carpomyiae* and *Omphalina* sp. parasitize fruit flies. Additionally, *Biosteres carpomyiae* and *Opius fletcheri* are known to parasitize fruit flies as well. *Pales murina* Mes. (Tachinidae: Diptera), an egg-pupal parasitoid, has also been found to infest the BFF. In southern Iran, the egg-pupal parasitoid *Fopius carpomyiae* (Silvestri) was recorded parasitizing BFF, with an estimated mean parasitization rate of 24% (71). The parasitoid *Opius concolor* was found infesting the third instar larvae of *C. incompleta*, with parasitization estimated at 26% (65). Another study (2023) recorded *Biosteres longicaudatus* (Ashmead) as an egg and pupal parasitoid of fruit flies in ber ecosystems. The parasitism rates of various Hymenopteran parasitoids of ber fruit flies are presented in Fig. 4 (73). Additionally, entomophagous fungi, *Clonostachys rosea*, were observed infecting BFF pupae. The LT50 (lethal time) of a conidial suspension of *C. rosea* ($1x10^{9}$ conidia/ml) on BFF pupae was found to be 4.6 days (74).

Chemical control

According to findings by (16), fruit fly control was achieved by spraying malathion (0.05%) in January. (30) explained that fenthion was most effective when administered three times during the season. Two sprays of malathion (0.05%), first on pea-sized fruits and then 15 days later, provided significant control (31). A field experiment conducted at Jobner, India,

Table 2. Different approaches in IPM and its impact on the management of BFF complex.

IPM Measures	Impact of its adoption
Raking and ploughing around the tree trunk	Exposing the hibernating pupae to sunlight and birds
Collection of fallen fruits	Reduction in further infestation of BFF
Destruction of off-season fruits	Reduction in breeding population
Resistant cultivars	Minimum percent infestation
	Tikadi, Katha, and Illaichi, Seo, Sukavani, Bhavnagari and Surti Kantha - Resistant - Nil infestation
	Safeda, Dandan, Gola, Goma Kirthi, Jogia, Narma, Mundia, Reshmi, Seb, ZG-3, Umran and Akharota - Moderately resistant
Volatile Chemicals -(Z)-3-hexen-1-ol acetate	Odour found in ber fruit may be evaluated for its efficacy towards attraction
Pheromone trap of Mediterranean fruit fly	Monitoring and mass trapping of fruit flies
Biocontrol agents - *Bracon fletcheri*, *Opius carpomyiae* and *Omphalina* sp	Increased parasitisation
Azadirachtin at 10,000 ppm @ 1ml/l	Minimum BFF infestation
One per cent extracts of Azadirachtin and *Ocimum sanctum*	Minimum BFF infestation
Spinosad 2.5 Sc@ 2ml/l	Minimum BFF infestation

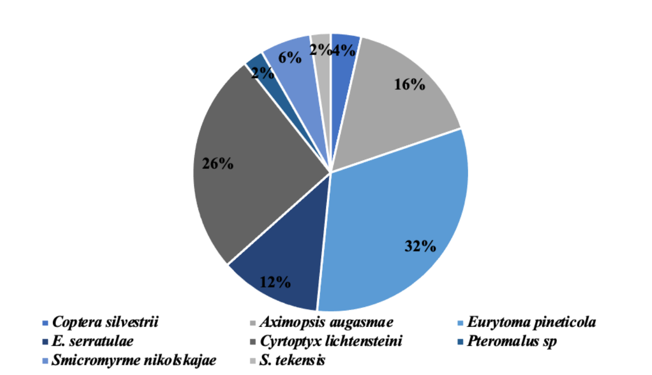

Fig. 4. Parasitism rate of different Hymenopterous parasitoids of ber fruit flies.

revealed that two foliar sprays of Spinosad 2.5 SC @ 2 ml/l, applied at two-week intervals starting from 50% fruit set, resulted in minimal infestation (1.17%) compared to the control (25.83%). The next most effective treatment was Azadirachtin (10,000 ppm) @ 1 ml/l, which resulted in 11.33% infestation. Spraying a combination of eco-neem and dimethoate significantly reduced infestation (7), while lambda -cyhalothrin (0.0025%) and beta-cyfluthrin (0.0018%) also showed a minimal incidence of *C. vesuviana* (37). The application of fenthion (0.1%) at the pea-sized fruit stage, followed by a second spray 30 days later, resulted in the least amount of fruit damage. According to (66), one percent extracts of Azadirachtin and *Ocimum sanctum* were effective for up to ten days after application. Notable chemical pesticides against ber fruit flies include Dipterex, Imidacloprid, Triazophos and Neem compounds (67) (36). (11) reported that an integrated management approach-consisting of Dipterex (100 g/acre), 5% molasses baiting, hoeing and collecting fallen fruits during the growing season-performed better than trees treated with a single method. According to (68), the use of tobacco extracts and neem powder significantly reduced damage caused by the BFF, making these treatments viable options for organic ber farming.

IPM Module

Recently, Punjab Agriculture University (PAU), Ludhiana recommended IPM module for eco-friendly management of guava fruit fly, *B. dorsalis* and *B. zonata,* on jujube in various regions of Punjab, India. This module includes (i) In the summer, raking the soil around the trees to expose the pupae to heat and natural enemies, (ii) Regular collection of infested fruits and burying them at least at 60 cm depth in pits, (iii) After harvesting, shallow ploughing with a cultivator exposing and eliminating pupating larvae and pupae, which are often found at a depth of 4-6 cm, (iv) Keep the field free from weeds and (v) Place PAU fruit fly traps (16 traps/per acre) during the first fortnight of February, replace trap after 1 month if required (72).

Conclusion

To develop effective control measures, a comprehensive study of the host range of the BFF is essential. Ber fruits are sometimes infested in conjunction with other fruit flies such as *Bactrocera correcta*, *B. dorsalis* and *B. zonata*. However, the extent of infestation and its seasonal patterns remain unclear, making the management of BFF in the ber ecosystem particularly challenging. A multifaceted approach is needed, addressing various aspects of pest management and resistance mechanisms. The use of biological control agents offers a promising solution for managing these pest populations, reducing dependency on chemical pesticides while enhancing the effectiveness of natural enemies and cultural practices. By integrating these strategies into comprehensive management plans, farmers and fruit producers can mitigate the impact of BFF while promoting sustainable agricultural practices.

Future prospective

The future prospects for addressing the challenge of fruit flies in the jujube ecosystem seem promising, thanks to innovative techniques and emerging research avenues. Currently, no known attractant compounds have been reported for *Carpomyia vesuviana*, similar to how Methyl Eugenol (ME) works for *Bactrocera* species. However, volatile collection methodologies combined with advanced gas chromatography techniques can help identify the intricate chemical profiles emitted by the fruit fly, leading to the development of potent attractants or repellents for targeted pest control. This species of fruit fly has shown no attraction to methyl eugenol, cue lure, or other pheromone traps, which highlights the need for alternative approaches. Electroantennography (EAG) studies could provide invaluable insights into the olfactory receptors of the fruit fly, aiding in the identification of key chemical cues involved in its host-seeking behavior. Additionally, exploring the plant's innate resistance mechanisms to fruit fly infestations is a promising avenue. Understanding the molecular pathways and identifying genetic markers associated with resistance can enable breeders to develop jujube cultivars with enhanced pest tolerance. Furthermore, Integrated Pest Management (IPM) programs tailored to the specific requirements of the region and crop can offer effective control of the ber fruit fly while minimizing environmental impacts and preserving crop quality. Wide-area management strategies such as insect transgenics, Sterile Insect Technique (SIT), embryo-specific lethality and Bait Application Techniques (BAT) remain underexplored but could be vital to future control efforts.

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Authors' contributions

KP was responsible for the planning, framework, editing and compilation of the review article and drafted the manuscript. BU contributed to editing and reviewing, while KJ participated in developing the concept, supervising the work and investigating the resources. KS and SS were involved in the study design, and provided supervision, editing and review of the manuscript. RK and ML were responsible for editing, resource acquisition and served as advisors. All authors read and approved the final manuscript.

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