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Changing scenario of fruit fly incidence in mango fruit tree ecosystem

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Abstract
The current knowledge on the occurrence, damages, comprehensive control of a pest involves the study of its invasiveness, biology, monitoring the population dynamics, effective management strategies. Mango is one of the important fruit among all the fruit crops in India as it covers the largest area and has the highest production yet the global market of India is less. Despite the fact that India is the world's leading mango producer, accounting for 44.14% of worldwide mango output, its market share is just 15%. The mango exports are mainly affected by the market circumstances and the threat of fruit flies. The Oriental fruit fly, *Bactrocera dorsalis* is the major polyphagous pest which causes damage to both quality and quantity with a vast host range. Species diversity and plant quarantine are the problems associated with fruit flies. During the harvesting stage, fruit fly destroys 35-40% of mangoes. Fruit fly infestation has been observed to result in a yield loss of up to 80% in mango. As a result, it is regarded as a significant quarantine pest in India. The environmental factors like temperature, relative humidity, light plays an important role in manipulating the fruit fly behavior. Studying these changing factors along with the multidisciplinary approaches which were adopted to study the characteristics of the flies helps in successful management of these insects using chemical cues, biological control methods and planning IPM strategies where annihilation technique plays a key role in controlling the flies.

Keywords: Invasiveness, polyphagous, host range, quarantine pest, IPM, annihilation technique

1. Introduction
Mango the national fruit of India is a tropical fruit crop, grows well even in subtropical regions but cannot withstand prolonged cold conditions. Mango grows well at a temperature of 27 °C. Many insect species infest the mango plants right from the nursery to harvesting of which fruit fly is one of the most common pests of mangoes which causes huge losses in both quality and quantity affecting the country's economy. The mango fruit fly is considered India's largest crop pest; these are serious problems and a major concern for mango growers and farmers. According to a 2015 research published in "The Hindu," the damage caused by these mango fruit flies accounts for around 27% of total mango harvesting. It was reported the production of fresh mangoes across the world from India is 21,033.58 MT which values at Rs. 271.84 crores 36.23 USD. (APEDA).

Of the major species infesting the mango, the oriental fruit is one problematic pest. The subfamily Dacinae is the most economically important of the three Tephritidae subfamilies. The genus Bactrocera is very significant in this subfamily since it contains economically important species like *B. dorsalis* (Hendel) and *B. zonata* (Saunders). Economically important species, such as *B. cucurbitae*, are found in the Zeugodacus subgenus (Verghese, *et al*., 2002) [9]. *Bactrocera dorsalis*, also known as the oriental fruit fly which previously known as *Dacus dorsalis*, is a tephritid fruit fly that is endemic to Southeast Asia. It is one of the most common pest species in the Bactrocera genus, having a wide range of cultivated and wild fruits as hosts. *B. dorsalis* had previously been found in over 150 hosts. The host range of the dorsalis complex has been limited to 117 species, belonging to 76 genera and 37 families, following the resolution of the dorsalis complex (Allwood, *et al*., 1999) [3]. In eastern India, it has also been found on the weed *Solanum indicum* L. (Agarwal, *et al*., 2019) [51]. Fruit flies have wide host range, short life cycle, great mobility and fecundity.

2. Systematics
Almost all Dacini species were formerly classified as belonging to the genera Dacus or Strumeta. This changed in the 1990s. It was decided in 2015 to further divide Bactrocera into Zeugodacus and Bactrocera, making Bactrocera the primary genus for the tribe (De Meyer, *et*

al., 2015) [47]. The Oriental fruit fly (*B. dorsalis*) is a member of the *Bactrocera dorsalis* species complex. This species complex is part of the Bactrocera subgenus, and its scientific name is *Bactrocera* (*Bactrocera*) *dorsalis*. The genus *Bactrocera dorsalis* was once thought to be a single species found across Asia, until Drew and Hancock (1994) [66] described *Bactrocera carambolae*, *Bactrocera papayae*, and *Bactrocera philippinensis*. Multidisciplinary teams conducted extensive research to delimit species boundaries using morphological, molecular, cytogenetic, behavioral, and chemo ecological data, which was largely coordinated under an FAO/IAEA Coordinated Research Project (CRP) on the 'Resolution of cryptic species complexes of tephritid pests to overcome constraints to SIT application and international trade. The international community (EPPO 2019, FAO 2019) [24, 26] has already finalised and widely accepted the taxonomic status of *B. papayae*, *B. phillippinensis*, and *B. invadens* as one and the same biological species, *B. dorsalis*, based on a multidisciplinary integrated approach after decades of uncertainty about its status (Schutze *et al*., 2015) [49].

2.1 Morphology of *Bactrocera dorsalis*

The Bactrocera species have a general and similar life cycle where the adult female deposits eggs under the semi-ripen or ripen fruits skin where the larval stages feed on the fruit tissues and reach the soil for pupation enclosed in a puparium. The adult emergence takes place. The time taken to complete this cycle depends on the temperature. *B. dorsalis* takes 37 days to complete this cycle at 25 °C (Vargas, *et al*., 1984) [70]. The adult females start laying eggs from 18 to 48 days from the emergence depending on the temperatures (Vargas, *et al.*, 2000) [65]. Larval duration ranges from 7-36 days at temperatures 35 and 15 °C respectively (Rwomushana, *et al.*, 2008) [33] where the pupal duration ranges between 9 to 34 days at temperatures 30 and 15 °C (Ekesi, *et al*., 2006; Rwomushana, *et al*., 2008) [71, 33].

2.2 Egg: The whitish, elongate, and elliptical egg measures around 1.17 x 0.21 mm and has no sculpturing on the chorion.

2.3 Larva: In general the larva is 10mm in length, creamy white maggot like curved posterior end and narrow anterior end. Each side of the cephalo-pharyngeal skeleton has a big convex, highly pointed mouth hook. The identification of the species based on the larva is not possible.

2.4 Adult: The adult is significantly bigger than a house fly, with a body length of around 8.0 mm and a completely hyaline wing of about 7.3 mm. This species is similar to *B. carambolae* in that it has a dorsalis complex colour pattern, including a pair of antennal spots and a black thorax with two parallel lateral postsutural vittae, but it differs in that it has a short ovipositor and a narrow costal band confluent with vein R2+3, as well as a short ovipositor (Orchards, M). The fly's color varies greatly, but the thorax has prominent yellow and dark brown to black patterns. The abdomen has two horizontal black stripes and a longitudinal median stripe that runs from the base of the third segment to the apex of the abdomen. Although these marks may make a T-shaped pattern, the shape varies greatly. The ovipositor is long and thin, with a sharp tip.

3. Fruit fly species identification infesting mango

The mango attacking Dacus species have been placed in the genus Bactrocera. The number of species occurring in Indian sub-continent are 325 of which 205 are from India (Kapoor 2005) [74]. The species which attack the mango in India includes: *Bactrocera dorsalis* (Hendel), *B. zonata* (Bezzi), *B. correcta* (Bezzi) and *B. caryeae* (Kapoor). *B. dorsalis* commonly known as the oriental fruit fly is considered the most important species which is widely distributed throughout the country and reported from south, south east, Hawaii and African continent (Kapoor, 1993; Chaudhary, *et al.*, 2016) [75, 37]. In India the insect undergoes pupal dormancy during the winters in the northern India because of the lower temperatures whereas in the south the insect remains active throughout the year as there is availability of wide range host plants like guava, custard apple, banana (Tandon, 1995) [63] and the other reason is the minimum temperatures in southern India which are favorable for the insect growth (Verghese & Sudha Devi, 1998) [8].

Oriental fruit fly (*Bactrocera dorsalis* (Hendel))

The size of the insect is medium with fulvous head which has two facial spots separately. Vitta on the post sutural median are absent. . The R2+3 and the coastal band are confluent. Leg segments are generally fulvous, with the exception of the fore-tibiae, which are pale fuscous, and the hind tibiae, which are fuscous. A thin transverse black band runs along the front border of tergum III, and a narrow medial longitudinal black band runs across all three terga. The anterolateral corners of Terga IV and V are narrow dark fuscous to black.

3.1 Guava fruit fly (*Bactrocera correcta* (Bezzi))

Bactrocera correcta is similar to the exotic *Bactrocera dorsalis*, but it has transverse facial spots which meets in the center, an extended apical wing spot instead of a continuous costal band, and microtrichia-free costal cells. At the apex of R4+5 an oval fuscous spot is present. It resembles *B. zonata* but has a scutum that is mainly black. The tibia of the hind leg is pale fuscous compared to the other leg segments which are fulvous. The identification of this species based on the morphological traits T mark on abdomen, thin black lateral margins on terga IV and V, anal streak restricted to cell cup oval spot across apex of wing at R, broad parallel sided lateral vittae enclosing is setae, both costal cells totally devoid of microtrichia.

3.2 Melon fruit fly (*Bactrocera cucurbitae* (Coquillett))

The face has two elongate large black spots, fulvous. Scutum is red-brown in color, postsutural vittae are present both laterally and on median, yellow scutellum. Costal band has developed into a large apical spot that stretches approximately half way to M. Presence of transverse marks on the crossveins r-m and dm-cu. A transverse band on the 3rd tergum along with the longitudinal bands over the 3rd to 5th segments forms the T-mark on the abdomen and also a transverse band on the 4th terga. It is attracted to the cue lure.

3.3 Peach fruit fly (*Bactrocera zonata* (Saunders))

Small circular black spots in medium size are present on the face. Median post sutural vittae are absent and two lateral vittae are present on the scutum. A small oval apical spot with a discontinuous costal band confluent with R2+3 and ending at the vein's apex. All segments of the legs are fulvous, except the hind tibiae, which are light fuscous. Presence of T patterns across the 3rd to 5th segments which may be reduced to narrow dark fuscous lines sometimes.

Table 1: Distribution

Species	Distribution	Attractant	Pest status
Bactrocera (*Bactrocera*) *dorsalis* (Hendel) (Oriental fruit fly)	Widespread in Indian subcontinent, across Southeast Asia and the northern Pacific	ME	Polyphagous
Bactrocera (*Bactrocera*) *zonata* (Saunders) (Peach fruit fly)	Sri Lanka, India, Pakistan, Nepal, Vietnam and Bhutan	ME	Polyphagous
Bactrocera (*Bactrocera*) *correcta* (Bezzi) guava fruit fly)	Cambodia, India, Bhutan, Myanmar, China (Yunnan, Guizhou), Nepal, Pakistan, Thailand, Vietnam, Malaysia (Peninsular), Sri Lanka, Bangladesh. USA-Florida (not established), California (eradicated)	ME	Polyphagous
Bactrocera (*Zeugodacus*) *cucurbitae* (Coquillett) (Melon fruit fly)	Endemic to the region from Pakistan and India across Southeast Asia. Now tropical and subtropical countries, also invaded Papua New Guinea, Solomon Islands, northern Pacific islands, northern Africa and Egypt.	CL	Polyphagous
Bactrocera (*Zeugodacus*) *tau* (Walker)	Widespread across south and Southeast Asia	CL	Polyphagous

(Reference: Vasudha, *et al*., 2019; Drew *et al*., 2007) [7, 67]

4. Importance (threat) of tephritid fruit fly in horticultural fruit orchards

4.1 Damage symptoms

All the species of the family tephritidae have similar life cycles and with similar damage symptoms. The adult fly oviposit on ripen or semi-ripen fruits of the host plant. The maggots after hatching feeds on the fruit pulp which results in secondary infestations with liquid oozing out and rotting. The last larval instar reaches the soil by jumping into the soil for pupation. The adults upon emergence continues the cycle.

4.2 Loses of fruit production

India ranks first in mango production in the world which accounts for 50% of the total world mango production. India during the year 2017-18 produced 21.8 million metric tons which contributed to the 40% of the world total mango production. *Bactrocera dorsalis* (Hendel), the oriental fruit fly is a polyphagous pest with wide range of hosts and the destructive pest which results in yield losses from 5 to 80% (Stonehouse, 2001) [1]. Bactrocera species are the most invasive species of horticultural crops which are of quarantine importance. The infestation and the losses in mango is based on the cultivar, season, and region. The fruit fly occur in all cultivars of mango but their severity varies depends on the cultivar like the late maturing cultivars have high susceptibility to fruit fly infestation as the timings coincide with the favorable conditions of the flies, the mid maturing cultivars have moderate infestation while the early maturing cultivars show less infestation as they coincide with the cold periods (Chatterjee, *et al*., 2006) [19]. The infestation of frit flies is less in cultivars Langra, Dashehari, Bombay green (Jothi, *et al*., 1994) [18] and the most susceptible cultivars are Banganpalli, Totapuri, Alphonso, and Kesari. The damage caused by the fruit flies reach upto 80% in epidemic regions (Abdullah, *et al*., 2002) [40]. It results in impacting the export market causing indirect losses because of the quarantine regulations imposed by the importing countries (Serem, 2010) [5]. It has an impact on both the quantity and quality of mango fruits, and is a present risks to mango production. Mango production loss ranged from 27 to 80 percent pre and post-harvest (Abdullah, *et al*., 2002) [40]. An estimated loss of Rs. 29,460 million in India have been reported due to fruit flies. The losses to a mango crop in unsprayed condition ranged from 2.5 to 59.0 percent in Bangalore, depending on the cultivars and variety. The least infested cultivars are dushehari and langra while the most infested cultivars are banganpalli and totapuri with infestation rates of 46.0 and 59.0 percent respectively. The *B. dorsalis* is reported to cause a crop loss of 5 to 70% in guava (Verghese, *et al*., 2002) [9]. Fruit fly infestation in guava, mango, and peach is a major bottleneck in the production of fruits (Bhalla, *et al*., 1977) [59].

5. Bionomics of tephritids fruit fly

5.1 Impact of climate change on population dynamics of fruit fly

Climate change impacts the insect pest populations affecting phenology, physiology, development, dispersion and ecosystem dynamics (Rashmi, *et al*., 2020) [46]. Climate change can have direct effects on an insect's physiology and behaviour, or indirect effects on the insect's host plants, natural enemies, and inter-specific interactions with other insects (Walther, *et al*., 2002) [28]. *B. dorsalis* lives mostly on its alternate host-plant, guava (*Psidium guajava* L.), during the off-season following mango harvest, completing multiple generations within a year (Kamala Jayanthi & Verghese, 2011) [62]. As a result, the availability of host fruits and the abundance of cultivated fruits were identified as critical variables in the survival of *B. dorsalis* (Harris *et al.*, 1993; Ye & Liu, 2005a, Kamala Jayanthi & Verghese, 2011) [23, 78, 62]. Aside from host-fruit availability, monthly average minimum temperatures were found to be a significant abiotic factor impacting fruit fly population dynamics (Liu & Ye, 1982; Verghese & Sudha Devi, 1998; Ye & Liu, 2005b: Kamala Jayanthi & Verghese, 2011) [77, 8, 79, 62]. The relevance of host plant phenological events in forecasting insect activity has been widely researched (Herms, 2004) [17]. Temperature is a major environmental variable that affects survival and development at each stage of life's development, as well as the rate of survival from egg to adult emergence.

5.2 Correlation with different weather parameters

Fruit factors such as maturity level, skin thickness, nutrient content, fruit color and size also influences the oviposition levels of the *B. dorsalis*. All the mango cultivars in India Banganpalli, Sindhri, Chunsa exhibit distinct features. Of these cultivars Chunsa has high nutrition which is beneficial for the larva development (Susanto, *et al.*, 2020) [20]. The weather parameters which show impact on the fruit fly population dynamics are the maximum and minimum temperatures, relative humidity (moisture), and rainfall and wind velocity.

5.2.1 Relative humidity

It is an important factor which directly affects the population of fruit flies. The minimum humidity has positive correlation with the fruit fly incidence (Laskar, *et al.*, 2010) [57]. The sunnier the day, the less fly activity in the area studied by researchers, while minimum humidity indicated that the sunnier the day, the less fly activity.

5.2.2 Temperature
The temperature variations are likely to have high impact on the rate of development of immature stages which affects the population growth of *B. dorsalis* (Choudhary, *et al*., 2017) [38]. The temperature has a major impact on the mature *B. dorsalis'* longevity and fertility. In adult females, longevity has reduced. Males had a comparable reaction to heat, but their lifespan was shorter. There were no eggs recovered, nor was there any intense activity of adults recorded at low temperatures, implying that there were no mating activities. Fecundity increased substantially with the temperature and vice versa. Females' pre-oviposition and oviposition periods differed based on temperature (Choi, *et al*., 2020) [41]. Cold stress appears to be the major limiting factor, preventing *B. dorsalis* from spreading and establishing in new regions (De Villiers, *et al*., 2016) [48]. During the summer, the population is higher than it is during the winter. These seasonal abundance variations might be explained by the effect of temperature on fruit seasonality. Temperatures below 21 °C slow down the growth of immature stages while the adults at temperatures between 25 °C and 30 °C produce the most eggs (Bateman, 1972) [13]. Fruit flies generate several overlapping generations per year and may breed at any time of year, if host fruits are available. This leads to unusually high populations, as well as significant losses in fruit and vegetable production.

5.2.3 Light
When it comes to fruit fly reproduction, light is critical, and it also impacts fruit fly behavior throughout the day. The most active time for virgin female flies is around night, with a lesser peak at morning. Mated females become more active as the light intensity rises, indicating ovipositional activity. In those species that mate at nightfall, increased light intensity in the morning promotes eating and egg-laying responses, whereas decreasing light intensity promotes mating responses. The intensity of light has an important influence in mating synchronization. When exposed to bright light rather than low light, certain species attain sexual maturity, mate, and lay eggs sooner, for example, *B. dorsalis* (Hendel). There have been correlations found between variations in fertility, changes in light and photoperiod, eating activity, and ovarian maturation rate.

6. Control and management strategies
The primary sources of losses includes improper handling and storage of fruits and vegetables from harvest to consumption, as well as deficient marketing channels. For the control of fruit pests, mango producers rely only on pesticides. Pesticide usage that is indiscriminate and injudicious results in pollution and pesticide residual issues (Rahiman, *et al*., 1986) [60]. In this regard, the current situation necessitates the implementation of an environmentally friendly pest management plan. Fruit fly control using full cover sprays began in the early 1900s with inorganic pesticides (e.g., lead arsenate) and continued throughout the century with synthetic insecticides like chlorinated hydrocarbons, organophosphates, and synthetic pyrethroids. Insecticide cover sprays have the advantages of being inexpensive, practical, and providing a high level of protection against fruit fly infestation with predictable outcomes. The addition of protein food baits to insecticide sprays lowered the quantity of pesticide needed to control fruit flies, and it has been employed successfully in many eradication projects. Reducing the fruit damage i.e. preventive measures and reducing the pest population are the strategies which are in use to prevent the losses.

6.1 Insecticide cover sprays
In several Asian countries, the use of pesticides sprayed as cover sprays to prevent fruit fly damage is common practice. Insecticides are highly potential chemicals when used appropriately, but when they are misused, they may cause a range of issues. Because certain fruits, such as mango, are seasonal and only produce one or two crops per year, pesticide use will be reduced. The widespread use of pesticide cover sprays to control fruit flies has resulted in several additional problems. Bait sprays and other alternative control tactics may be more effective and safer.

6.2 Baits
In the early 1950s, insecticidal protein baits (mixtures of protein hydrolysates and insecticides) were effectively used to control *B. dorsalis* in field experiments in Hawaii (Steiner, 1952) [42]. Protein baits are designed to attract female species which are looking for a protein source to help them reach reproductive maturity (Steiner, 1957) [43]. Steiner (1952) [42] studied the effectiveness of various protein concentrations in attracting *B. dorsalis* and discovered that baits with a greater protein content were more appealing to the species. Organophosphates were shown to be the most effective toxicants for use with protein baits in previous research on bait sprays for fruit fly control (Steiner, 1957) [43]. In the following years, mixtures of protein hydrolysate and organophosphates like Malathion were successfully utilized to eliminate *B. dorsalis* in several parts of the world. Reduced risk toxicants were sought in the late 1990s and early 2000s for use in conjunction with protein baits to control fruit flies, especially *B. dorsalis*. Spinosad, generated from the soil-dwelling actinomycete bacteria *Saccharopolyspora spinosa* Mertz and Yao, and Phloxine B, a photoactive xanthene dye, were shown to be effective alternatives for malathion in the control of *B. dorsalis* in combination with protein baits (McQuate, *et al.*, 2005; Vargas, *et al.*, 2006) [29, 69].

6.3 Crop hygiene
As a result, orchard cleanliness should play a key role in controlling the pest's proliferation (Theron, *et al.*, 2017) [15]. However, only a few studies have looked at the influence of orchard cleanliness alone on *B. dorsalis* populations. Verghese, *et al*., 2004 [10] found that weekly fruit removal combined with frequent ploughing and raking of soil for the destruction of fruit fly pupae and restricted insecticidal sprays greatly decreased mango infestations in Indian mango plantations. For *B. dorsalis*, the most effective approach to dispose of fallen fruit or fruit left over after harvest is currently unknown. For the melon fly, *Z. cucurbitaceae*, the use of a tent-like structure called an augmentorium for catching adult flies emerging from fruit gathered from the ground and after harvest has been proven to be successful (Klungness, *et al*., 2005) [45]. The effectiveness of such a structure as a *B. dorsalis* orchard sanitation method should be examined.

6.4 Physical techniques
A management strategy that appears to be unique to some Asian nations is wrapping or bagging fruit with paper bags to inhibit oviposition and so produce fruit fly-free fruit even in the presence of high adult fly populations (Zhao J P, *et al.*,

2017) [39]. Carambola, for example, has been grown in Malaysia using this method for over 70 years. Mango cultivation in the Philippines, notably on Cebu Island (Hapitan & Castillo, 1976) [35], and a variety of fruit crops in Taiwan also use fruit wrapping (Hapitan & Castillo, 1976; Cheng, *et al*., 1991) [35, 14]. Langra is a variety of mango. Fruit fly control is accomplished by bagging 30 days before to harvesting in black polybags and brown paper bags (100%) (Sarkar, *et al*., 2009; Islam, *et al*., 2019) [20, 73].

6.5 Phytosanitary treatment
The phytosanitary treatments include the hot treatment, cold treatment and the irradiation techniques. Heat tolerance decreased as 1st and 2nd instar *B. dorsalis* became older, but increased as 3rd and 4th instars grew up, according to Kaneyuki, *et al*., (2016) [50] *in vitro* research. In an artificial diet, a high density of larvae produced metabolic heat and a higher rearing temperature than a low density. When raised at higher temperatures between 20 and 35 °C, 3rd instars were more tolerant to *in vitro* immersion in hot water at 43 °C (Miyazaki & Dohino, 2000) [32]. Existing phyto-sanitary heat treatment schedules against *Bactrocera dorsalis* in India are: Export of mango from India to Australia needs heat treatment of 46.5 °C and hold for 30 min or to 47.5 °C and hold for 20 min (Minimum treatment time 2 h) for control of *B. dorsalis*, *B. cucurbitae* (DAFF Australia 2014) [22], for exports to japan 47.5 °C and hold for 20 min *B. dorsalis* complex , *B. cucurbitae* (MAFF Japan 2015) [54] and for new Zealand 48 °C and hold for 20 min to control *B. caryeae*, *B. correcta*, *B. dorsalis*, *B. zonata*, *B. cucurbitae*, *B. tau* (MPI NZ 2014) [55]. Ionizing radiation at 150 Gy, the general dosage allowed for all Tephritidae, is the most commonly used therapy (IPPC 2009) [34]. More fresh fruits tolerate this dosage than any other commercially available therapy (Heather and Hallman 2008) [58]. Phytosanitary irradiation is still notl accepted in some markets (Follett, 2014; Hallman & Loaharanu, 2016) [61, 64]. More study is needed to show the efficacy of irradiation with cold combo treatments while monitoring commodity quality.

6.6 Biological control
Natural enemies (parasites and predators) can be used to control pest populations since they are reasonably harmless, long-lasting, and cost-effective. Thailand, Malaysia, and India (Agrawal and Mathur, 1991) [1] have all recorded several parasitic and predatory species. Using hymenopteran parasites imported from Malaysia and nearby nations, a large biological control operation against the Oriental fruit fly was carried out in Hawaii from 1947 to 1952. (Bess, *et al*., 1961) [30]. EPNs have been found to be virulent against a variety of fruit flies, with varying degrees of efficiency. Because of their foraging habit, EPNs may actively look for and eliminate pests inside the fruits (Sirjani, *et al*., 2009; Barbosa-Negrisoli, *et al*., 2009) [25, 16]. However, the majority of research has concentrated on using EPNs on fruit fly soil-dwelling stages. The effectiveness of several EPNs against *B. dorsalis* was tested in the laboratory (Godjo, *et al*., 2018; Aatif, *et al*., 2019) [2, 31]. Against *B. dorsalis*, only *Heterorhabditis bacteriophora*, *Steinernema carpocapsae*, *Heterorhabditis marelata*, *Heterorhabditis indica*, and *S. asiaticum* were tested.

6.7 Sit (Sterile insect technique)
In the early 1960s, sterile insect releases were used to control *B. dorsalis* (Steiner, *et al*., 1962) [44]. Irradiation was used to induce sterilisation. To remove *B. dorsalis* from the Mariana Islands, researchers mass raised, irradiated, and released a white marked strain discovered from a natural population on the island of Rota (Steiner, *et al.*, 1962) [44]. The breed was created to make it simpler to distinguish between wild and irradiated flies. Following that, a translocation-based genetic sexing strain of *B. dorsalis* based on pupal colour mutations (males are brown and females are white) was produced, and in pilot field experiments in Thailand (Isasawin, *et al*., 2012) [72], it showed promise for the control of *B. dorsalis*. Transformer genes that may be targeted by RNAi to produce a male-only *B. dorsalis* strain have recently been identified and described (Liu, *et al*., 2015) [27]. Such strains have yet to be evaluated in this field, which is still in its early stages. Between 1999 and 2000, SIT targeting *B. dorsalis* in combination with other management strategies such as orchard cleaning and pesticide sprays, particularly when administered area wide, was beneficial in reducing *B. dorsalis* infestation of mangoes in Thailand (Manrakhan, 2020) [4]; (Orankanok, *et al*., 2007) [76]. Furthermore, the Sterile Insect Technique (SIT) necessitates bulk rearing of the target pest and geographic separation of the release zone (Suckling *et al.*, 2016) [21].

6.8 MAT (Male annihilation technique)
Male Annihilation Technique (MAT) is an important strategy to control or eradicating pestiferous tephritid fruit flies for which potent male lures are available (Manoukis, *et al.*, 2019) [56]. Current MAT implementations for *Bactrocera dorsalis* (Hendel) species, combine the male attractant methyl eugenol (ME) with a toxicant administered at a high density with the purpose of attracting and killing the males. It is used to track and assess population size as well as to eliminate males as a pest management measure.

7. Conclusion
The post-harvest losses caused by the tephritid fruit flies are the major impediments for exports in fruits and vegetables. Fruit fly field identification based on taxonomy is a reported need that should be addressed. Gautam, *et al.*, (2015) [68] great attention to detail morphological features such as body color and size, color pattern, and the presence of thoracic vittae as useful tools for field identification. And the changing scenarios also play an important role in the population dynamics of the fruit fly in the mango orchards. Studying the temperature-dependent connection between host-plant phenology and pest incidence, on the other hand, would undoubtedly aid in understanding and assessing the impact of climatic changes on host-plant and pest interactions. There have been several advancements in biological control methods, SIT, quarantine treatments, and next-generation instruments mentioned (Ali *et al*., 2016, 2017) [11, 53]. Fruit fly management research in the future will necessitate a continuous emphasis on IPM concepts as well as an expansion of the focus beyond pest control.

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