Pest bioecology and management strategies for the genus *Bactrocera* (Diptera: Tephritidae)

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Abstract

Fruit flies a significant pest in the genus *Bactrocera* (Diptera: Tephritidae), can easily infect agricultural crops like fruits, nuts, and vegetables around the world. More than 170 varieties of vegetables and fruits are seriously affected by *B. dorsalis, B. cucurbitae, B. zonata, B. tau, B. tryoni, B. correcta, B. latifrons, B. olae* in India. The situation deteriorates when these pests are controlled with chemicals that create secondary pest outbreak, pest reawakening, and development of pesticide resistance as well as emergence of pest biotypes, and regulatory complications in the agro ecosystems. To protect the environment and the crops, there has to be an alternative way to terminate these pests. The literature review gives a comprehensive overview on the genus *Bactrocera*. The paper focuses on bioecology and management strategies for the pest, as well as the key gaps in literature for sustainable management of this pest in near future.

Keywords: *Bactrocera*, agro ecosystem, bioecology, sustainable management

Introduction

Globally, fruit flies in the genus *Bactrocera* (Diptera: Tephritidae) are economically important pests of agricultural crops including fruits, vegetables, and nuts all over the world (Drew *et al*., 1994; Jiang *et al*., 2017; Liu *et al*., 2019) [13, 31, 42]. The Oriental fruit fly *B. dorsalis* is the most virulent and serious fruit fly species that infests more than 70 species of tropical and subtropical fruits and melons, representing 35 plant families, such as guava, water apple, rose apple, mango, cashew, cherry, orange, banana, etc. (Vargas *et al*.,2015; Kunprom *et al*. 2015; Jiang *et al*., 2017; Zeng *et al*., 2019) [80, 40, 31, 84]. They cause great economic threats worldwide by hampering the fruit and vegetable industry (Gu *et al*. 2019) [19]. An overview of 73 pest species of *Bactrocera* examines recent developments of reduced risk technologies for their control, and employs the required Integrated Pest Management (IPM) programs. IPM is the one of the best methods to control this notorious pest without damaging the environment. *Bactrocera* species are categorized under four groups based on pest severity, host range, invasiveness, and frequency of infestation (Clarke *et al*., 2022) [9]. In Pakistan and all over the world, *Bactrocera zonata* (Saunders.), the Peach Fruit Fly (PFF), and *Bactrocera cucurbitae* (Coquillett.) the Melon Fruit Fly (MFF), are considered severe and polyphagous insect pests of various fruits and vegetables (Saeed *et al*., 2022) [63]. In India, *Bactrocera dorsalis*, the Oriental fruit fly, is widely spread in Andaman and Nicobar Islands, Andhra Pradesh, Assam, Bihar, Chhattisgarh, Delhi, Goa, Gujarat, Himachal Pradesh, Jammu & Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Mizoram, Odisha, Punjab, Rajasthan, Haryana, Sikkim, Tamil Nadu, Telangana, Uttarakhand, Uttar Pradesh, West Bengal (Nugnes *et al*.,2018) [55]. The excessive use of synthetic pesticides to manage agricultural pests results in environmental pollution and health hazards while IPM is truly effective to control the destructive pest (Nehra *et al*., 2019c) [52].

Bioecology

Development of the genus *Bactrocera* from egg to adult depends on temperature, humidity, rainfall and several biotic factors. Warmer temperatures speed up development cycle rather than cool temperatures (Drew *et al*., 1994; Jalaluddin *et al*., 1999) [13, 29]. Female flies insert eggs in small cluster inside the mesocarp of the ripe fruits. The eggs are mostly white in colour up to 1/16 of an inch long (Robinson *et al*., 1989; Fiaboe *et al*.,2021) [61, 15]. Whereas newly hatched larvae are feeding on the pulp which appears normal from outside. There are three larval stages (instars). The larva of fruit fly is elongated, legless, cylindrical- maggot shape, anterior end narrowed, flattened caudal end, and creamy white colour. Larva ranges in length from 1/16-3/8 of an each. Larval feeding damage in fruits is the most damaging. (Robinson *et al*., 1989; Drew *et al*., 2002) [61, 15]. The body of the first instar is about 4 mm in length and 1 mm width (Robinson *et al*., 1989) [61]. The 2nd instar is 5 mm in length and 1-1.5 mm width. The body changes into creamy colour. The 3rd stage of larvae has been finished the feeding stage. After completing larval development, the larvae leave the host fruit, and entered into the sawdust. In this stage the larva is very jumpy. After completing larval development, the mature larva emerges from the fruit. Pupation normally occurs 1-2 inches under the soil (Robinson *et al*., 1989) [61]. Development from egg to adult takes 22-24 days (Drew *et al*., 1994) [13].

Host range of *Bactrocera*

Fruit flies are the main pests for solanaceous crops and cucurbits (cucumber, zucchini, melon, etc.) (Kuber *et al*., 2010) [38]. *B. cucurbitae* is the major pest of cucumber (*Cucumis* *sativus* L.), Bitter gourd (*Momordic acharantia*), young Tomato (*Solanum lycopersicum*), Mahogany seed (*Swietenia macrophylla*), Eucalyptus leaves (*Eucalyptus globulus*), Black plum leaves (*Syzygium cumini*), Jackfruit leaves (*Artocarpus heterophyllus*), Neem leaves (*Azadirachta indica*), Black pepper (*Piper nigrum*) and Garden croton leaves (*Codiaeum variegatum*) (Sultana *et al*.,2020) [75]. Essential developmental and reproductive attributes of the *B. dorsalis* (Hendel) were studied on five host fruits viz., mango (*Mangifera indica*), papaya (*Carica papaya*), guava (*Psidium gaujava*), sapota (*Achras zapota*) and banana (*Musa acuminate)* at 27±1 °C and 65% RH (Kalia *et al*.,2005) [32]. Comparative host preference for both the species *Bactrocera carambolae and Bactrocera dorsalis* were studied with regards to malaya varieties of star fruit (*Averrhoa carambolae*), manalagi varieties of mango (*Mangifera indica)*, guava aka water apple (*Psidium guajava*), citra water guava (*Eugenia aquae*), jamaica bol guava (*Eugenia malaccenensis*), and california papaya (*Carica papaya*) (Koswanudin *et al*.,2018) [36].Guava was the most suitable host of fruit flies followed by Kinnow, pear and peach (Singh *et al*.,2013) [73]. Fruit fly (*Bactrocera correcta* Bezzi) is the major pest of Guava grown in Baruipur region of West Bengal, contributing upto 90% yield loss (Mondal *et al*., 2015) [15]. The olive fruit fly *Bactrocera oleae* is one of the key insect pests infesting olive orchards in Mediterranean areas (Rossini *et al*., 2022) [62]. *Zeugodacus cucumis* and *Bactrocera jarvisi* are pests of fruit and vegetable crops and damage horticulture industries (Liu *et al*., 2019) [42].

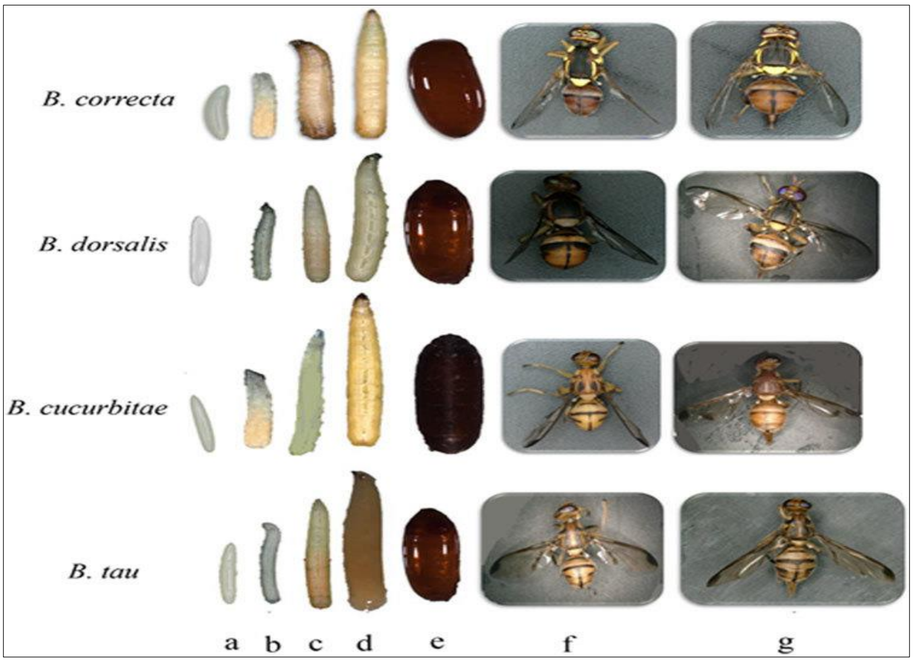

Fig 1: Different stages of *Bactrocera* species fed on the semi-artificial diet. (a) egg; (b) first instar; (c) second instar; (d) third instar; (e) pupa; (f) male adult; and, (g) female adult (Source: Jaleel *et al*., 2018) [30]

Management strategies

Physical management

A sweeping electronic nose system (SENS) was self-developed to detect the presence of early infestation by *B. dorsalis* (Hendel) in citrus fruits (Wei *et al*.,2019) [82]. Automatic pest detection is a useful method for greenhouse monitoring against pest attacks (Ebrahimi *et al*., 2017) [14]. Efficacy of different wooden blocks as dispenser block of methyl eugenol (Male Annihilation Technique) for attraction of *Bactrocera* species has been studied (Kumar *et al*.,2022) [39]. Bagging is also an important strategy for the control of fruit flies. Among the traps and baits (pheromone trap, mashed sweet gourd trap, indigenous food bait and banana pulp bait), pheromone trap can be used for controlling fruit fly on bottle gourd (Alam *et al*., 2021) [2]. Several non-chemical approaches, such as bagging fruits with double-layer brown paper bags, cloth bags, polythene bags, and installing methyl eugenol kairomone traps and protein hydrolysate bait lures, were evaluated (Islam *et al*., 2017) [27]. Various fruit covering materials bagging with yellow coloured polythene has been found improves the overall physico-chemical quality of winter season guava (Meena *et al*., 2016) [48].

Chemical management

Spinosad, Indoxacarb, and Acephate are most effective control measures against fruit fly *B. cucurbitae.* Spinosad is the best bio-pesticide against Cucurbit fruit fly in bottle gourd, with Dichlorovos and Lambda-cyhalothrin next in order, while Jholmal and Azadirachtin offer a better quality of fruits and higher yield in bottle gourd (Gautam *et al*., 2021) [18]. Seed treatments with thiamethoxam, spraying emamectin benzoate, installation of cue lure traps have also been used to control this pest Reynolds *et al*., (2017) [60]. Fenthion, emamectin benzoate, and abamectin have the greatest effect on adult mortality and offspring production. Infested fruits treated with acetamiprid, fenthion, and thiacloprid produce no or very few offspring. Alpha-cypermethrin is a possible alternative to fenthion against *B. tryoni*. Thiacloprid and Acetamiprid may be useful as a post-harvest treatment (Nehra *et al*.,2019c) [52].

Botanical management

Deltamethrin, Azadirachtin and indoxacarb are very effective in minimizing the fly population and reducing fruit damage (Vasudev *et al*., 2015) [81]. Neem oil was inferior to Spinosad which was followed by the treatment of Abamectin, Allamanda leaf extract and Mahogany oil (Alam *et al*., 2021) [2]. Azadirachtin has excellent bioactivities against *B. dorsalis* larvae (Zhou *et al*.,2020) [85]. Neem leaves (*Azadirachta indica*) and Ginger (*Zingiber officinale*) extracts can be used as bio-pesticide for eco-friendly control of cucurbit fruit fly infestation in cucumber field (Sultana *et al*.,2020) [75]. Vasudev *et al*., (2015) [81] had focused on the evaluation of methanol and acetone bark extracts from *Acacia nilotica* (Linn.) as a source of growth inhibitors against *Bactrocera cucurbitae*. Significant effects of the extracts were observed on the activity of Glutathione S-transferase, esterases and catalases in the second instar larvae of *B dorsalis*.

Biological management

Fopius arisanus, *D longicaudata*, *Fopius vandenboschi* (Natural parasitoids). Garcia *et al*., (2012) [17] had focused on biological control using parasitoids for fruit fly management *D. longicaudata* was chosen due to its specificity for the family Tephritidae and its ease of laboratory rearing. FALMs [(Fruit juice/pulps Admixed with LureMixtures (LM))] were assessed for their attraction against melon fruit flies under laboratory and field conditions (Shinwari *et al*., 2015) [72]. Entomopathogenic nematodes as biological control agent against *Bactrocera zonata* and *Bactrocera dorsalis* (Diptera: Tephritidae). Ten different species of entomopathogenic nematodes (EPNs) *Heterorhabditis bacteriophora*, *H. megidis*, *H. georgiana*, *H. floridensis*, *H. indica*, *Steinernema carpocapsae*, *S. riobrave*, *S. feltiae*, *S. rarum* and *S. glaseri* against different developmental stages i.e., larvae, pupae and adults of fruit fly species *Bactrocera zonata* and *Bactrocera dorsalis* (Zida *et al*.,2019) [86].

Ecological management

Eco-friendly and novel technologies comprising ploughing, sanitation, male annihilation technique (methyl eugenol- based traps) and bait application technique (protein hydrolysate plus spinosad) are used for controlling the fruit flies (Singh *et al*., 2020) [73]. Methyl eugenol pheromone traps (PAU traps) may be used as ecofriendly management of fruit flies (Sharma *et al*., 2022) [69].

Table 1: List for management strategies of the genus *Bactrocera*

***Bactrocera* species**	**Chemical controls**	**Botanical controls**	**Biological controls**	**References**
Bactrocera cucurbitae (Coquillett)	Insecticide,defensive enzymes peroxidase, superoxidase dismutage,polyphenol oxidase, catalase.	Methanole and acetone bark extracts from *Acacia nilotica*,spinosad, Jholmal and Azadirachtin. Neem oil with Abamectin, Allamanda leaf extract, Mahogony oil, mashed sweet gouard trap	SIT (Sterile Insect Technique) Protien food baits (Malathion), Parasitoids (*D. longicaudata*), Methoprene Application, Pheromone trap, Male Annihilation technique (MAT), Coloured traps, Bait Application Technique (BAT), Cue-lure (CL)	Vargas *et al*., (2015) [80]; Garcia *et al*., (2012) [17] Haq U *et al*., (2013) [21] Somegowada *et al*., (2021) [74] Vasudev *et al*., (2015) [81] Alam *et al*., (2021) [2]
Bactrocera dorsalis (Hendel)	Chlorinated hydrocarbons, organophosphates, and synthetic pyrethroids, Semiochemicals.	Carvacrol toxic essential oil. (*Seriphidium brevifolium*, *Piper nigrum*,*Azadirachta indica* and quercetin), Spinosad	*Fopius arisanus*, *D longicaudata*, *Fopius vandenboschi* (Natural parasitoids) Bagging fruits (double layer brown paper bag), ME MAT Technique (Methyle eugenol-male annihilation technique)	Hee *et al*., (2015) [22] Clarke *et al*., (2022) [9]; Vargas *et al*., (2012) [80]. Jaffar *et al*., (2022) [28] Jaleel *et al*., (2020) [30]
Bactrocera zonata (Sounders)	Pesticide and Bait Spray.	Neem oil	Parasitoids, Soil Drenches, Fruit Stripping. Delta shaped Jackson trap, liquid lure.	Clarke *et al*., (2022) [9]
Bactrocera carambolae Drew &Hancock	Soil drench, Diazinon insecticide.	Neem extract	Delta trap and round trap. ME (Methyl eugenol) attractant. Wrapping	Susanta *et al*., (2022) [76]
B.correcta (Bezzi) Guava fruit fly	Dichlorvos spray	*Piper nigrum*	Pheromone trap (Bacu lure) Bagging, Wrapping	Mondal *et al*., (2015) [50] Jaleel *et al*., (2020) [30]
Bactrocera latiforns (Hendel)	Insecticides cover spray or a bait spray.	Cade oil (etheric oils,triterpene and phenols)	Sanitation, SIT (Sterile Insect Technique)	McQuate *et al*., (2013) [45] Clarke *et al*., (2013) [9]. McQuate *et al*., (2007) [46]
Bactrocera oleae (Gmelin) olive fruit fly	Triterpenic dialcohols most insensitive to dimethoate.	Neem oil. Spinosad	*Psyttalia lounsburyi*, *Psyttalia concolor*, *Psyttalia ponerophaga*, *Utetes africanus*, and *Bracon celer*. *Bacillus thuringiensis* (Bt),	Somegowada *et al*., (2021) [74] Vasudev *et al*., (2015) [81] Alam *et al*., (2021) [2]
Bactrocera tryoni (Froggatt)Queensland fruit fly.	Fenthion,emamectin benzoate, and abamectin, dimethoate	Protein-bait spray	Cue-lure in males. Male annihilation technique	Reynolds *et al*., (2017) [60]
Bactrocera tau (Walker)	Organophosphate insecticides (e.g., malathion, diazinon, and naled)	Neem oil	SIT (Sterile insect technique) MAT (male annihilation technique)	Clarke *et al*., (2022) [9]

Discussion

Fundamental research into the dispersion, mating and oviposition behaviour, population dynamics and estimation of density, eradication models, spatial distribution, genetics, and evolution of the melon fly have been undertaken, which eventually lead to the success of the eradication project against the notorious pest (Koyama *et al*., 2004) [37]. The fruit fly population is influenced by abiotic parameters such as temperature, relative humidity, rainfall, and total sunshine hours per day (Mutamiswa *et al*., 2020) [51]. Herbivores are generally affected by host primary metabolites for their general vitality, growth and reproduction, while consumption of Secondary metabolites (phenols, flavonoids, tannin, alkaloids, phytate, etc.) are responsible for reducing their adult longevity, fecundity and retardation of larval growth (Ganie *et al*.,2012) [16] The study of pest population dynamics is a widely used technique in insect pest management (Ganie *et al*.,2012) [16]. Jaleel *et al*., (2019) [30] described the two-sex life table parameters of four species in the genus *Bactrocera*, viz., *B. correcta, B. dorsalis, B. cucurbitae* and *B. tau*, fed on semi-artificial diet. The age-stage, two-sex life table can eliminate many of the inherent error characteristics of female-based traditional life tables (Kumar *et al*.,2022) [39]. Only a few studies have focused on two sex life table traits of *B. cucurbitae* on cucumber and *B. dorsalis* on mango (Huang and Chi, 2014; Mohamed *et al*., 2019) [25,49]. The development time of immature stages and pre-oviposition period of their females varied with food resource, like *B. cucurbitae* (Huang and Chi, 2012) [25]. *B. dorsalis* shows almost similar life-history attributes like *B. cucurbitae* and *B. correcta* on the selected fruit diets (Liu *et al*., 2013; Gu *et al*., 2019) [41,19]. *Bactrocera* species exhibit a wide range of host plant preferences and have significant impacts on agricultural production. Further research is needed to understand the factors influencing host selection, host suitability,and the mechanisms of host adaptation. This knowledge could contribute to the development of targeted pest management strategies and host plant resistance breeding program. Some *Bactrocera* species have become invasive pests in region outside their native range. Investing the factors contributing to their successful establishment and spread in new areas would be valuable for implementing effective quarantine measures and preventing further introductions. Understanding the pathways of introduction, the role of human activities, and the factors influencing the invasive potential of *Bactrocera* species could help inform biosecurity measures and risk assessment frameworks. *Bactrocera* species have developed resistance to various insecticides, posing challenges for their control. Further research is needed to study the mechanisms of insecticide resistance, including target site mutations and detoxification enzyme activity. Additionally, alternative pest management strategies, such as the use of biological control agents, semiochemicals and behavioural manipulation techniques, would be beneficial for sustainable pest control.

Conclusion

Fruit flies are major constraint in agricultural production throughout the world including tropical and subtropical Asia. *Bactrocera* attacks a wide range of different fruits, vegetables and also leads for quantitative and qualitative losses. Integrated Pest Management (IPM) is the most appropriate method to manage the destructive pests without damaging the environment. For sustainable agriculture, life table parameters, feeding dynamics, economic injury level and economic threshold are most important analytical tools. Life table study is a central theme in ecological research to understand the temporal and spatial patterns in population dynamics. *Bactrocera* can be handled globally by multiple components through reduced risk technologies to control. A biological barrier to the introduction of new fruit fly populations reduces the source of outbreaks and the risk of species spread, and decreases the use of insecticides on fruit destined for domestic and foreign markets. So, exploring alternative pest management strategies would be beneficial for sustainable pest management in near future.

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