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Review Paper

Fruit Flies: Fauna, Bio-ecology, Economic Importance and Management with an Overview of the Current State of Knowledge in the Sultanate of Oman and the Arabian Peninsula

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ذباب الثمار: أنواعه، حياته-بيئته، أهميته الإقتصادية، ومكافحته، مع استعراض للمعلومات الحالية عنه في سلطنة عمان وشبه الجزيرة العربية

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Abstract.

Fruit fly species are important pests of fruit trees and vegetables.They cause significant economic losses due to the damage they cause to fruit and quarantine regulations preventing fruit export. This review was divided into two sections: a general world summary of the currently available literature on fruit flies and a more focused summary of fruit flies in Oman and neighboring countries of the Arabian Peninsula. The world summary covered the latest available information about fruit flies in terms of their general taxonomy, feeding patterns, life cycle, host plants, natural enemies, economic importance, and management tactics. Information was presented about the most recent management techniques, such as augmentoriums, chemosterilants, Wolbachia caused sterility, and auto-dissemination devices. This review also examined the available information about fruit flies in Oman and the Arabian Peninsula in terms of the fauna, economic species, bioecology, and pest management. Twenty tephritid species are known from Oman, and total number of described species from the Arabian Peninsula is 115, with most of the species belonging to the less economic subfamily Tephritinae. Most of the research works about bioecology and pest management of fruit flies comes from Oman, with only three articles from the rest of Arabia. The available regional literature examined are fruit fly surveys based on sampling of fruits and lure traps, and identifications of fruit fly species, their host plants, and parasitoids. It also included population dynamics of the common peach fruit fly in AlBatinah using lure traps, difference in infestations among fruit types, and a comparison of the effectiveness of different lures and trap designs. Finally, we present a summary of research from Oman and the Arabian Peninsula about insecticide trials and physical barriers (fruit bagging and row covers). Researchers in this region should focus on the less touched aspects alluded to in the general review such as biological control using natural enemies, sterile insect methods including the promising use of chemosterilants, and area-wide integrated pest management.

Keywords: Tephritidae, fauna, natural enemies, host plants, IPM

الملخص:

ذباب الثمار هو آفة مهمة بالنسبة لأشجار الفاكهة والخضروات، ويحدث خسائر اقتصادية كبيرة من خلال الضرر الذي يحدثه على الثمار وبسبب القوانين التنظيمية للحجر الزراعي التي تمنع تصدير الثمار. هذه المراجعة تم تقسيمها إلى جزئين: ملخص عالمي عام عن الأدبيات المتوفرة حاليا حول ذباب الثمار، و ملخص أكثر تركيزا عن ذباب الثمار في عمان والدول المجاورة في شبه الجزيرة العربية. غطى الملخص العالمي أخر ما توفر من معلومات حول ذباب الثمار فيما يخص التصنيف العام، أنساق التغذية، دورة الحياة، النباتات المعيلة، الأعداء الطبيعية، الأهمية الاقتصادية، وأساليب المكافحة. تم استعراض معلومات عن طرق المكافحة المستجدة مثل الداعمات، المعقمات الكيميائية، التعقيم الذي تسببه *Wolbachia* ، وأجهزة النشر التلقائية. نظرت هذه المراجعة أيضا إلى المعلومات المتوفرة عن ذباب الثمار في عمان وشبه الجزيرة العربية من ناحية الأنواع المتواجدة، والأنواع الإقتصادية، وحياة-بيئة الأنواع، ونظام المكافحة. هنالك ٢٠ نوعا من ذباب الثمار معروف تواجدها في عمان، والمجموع العام للأنواع الموصوفة من شبة الجزيرة العربية هو ١١٥، مع العلم ان معظم الأنواع تعود للمجموعة ما تحت العائلة Tephritinae الأقل أهمية اقتصاديا. معظم العمل البحثي عن حياة-بيئة ومكافحة ذباب الثمار أتى من عمان، فهناك فقط ثلاث مقالات، ذات صلة، تعود لبقية الجزيرة العربية. إن الأدبيات المتوفرة من المنطقة التي تم فحصها هي مسوحات لذباب الثمار مبنية على اخذ عينات من الثمار ومن المصائد الجاذبة، وتعريفات لذباب الثمار المجمع، وعوائله النباتية، وأعدائه الطبيعية. شملت الأدبيات أيضا التغيرات العددية لذبابة ثمار الخوخ الشائعة في الباطنة باستخدام المصائد الجاذبة، والتباين في الإصابة بين أنواع ثمار الفاكهة، والمقارنة بين أنواع مختلفة من المواد الجاذبة وتصاميم المصائد. أخيرا، نعرض ملخصا للبحوث المتعلقة بتجارب المبيدات والحواجز الفيزيائية (تكييس الثمار وتغطية الخطوط المزروعة) من عمان والجزيرة العربية. على الباحثين في المنطقة ان يركزوا على الجوانب التي لم تطرق بشكل كاف، حسب ما تبين من المراجعة العامة، مثل المكافحة الحيوية باستخدام الأعداء الطبيعية، طرق التعقيم الحشرية شاملة الاستخدام الواعد للمعقمات الكيميائية، والإدارة المتكاملة للآفات على نطاق واسع عبر المساحات الزراعية

الكلمات الرئيسية: عائلة ذباب الفاكهة الحقيقي، الأنواع الحيوانية، الأعداء الطبيعية، النباتات المضيفة،الإدارة المتكاملة للآفات

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Introduction

Crop plants are the principal food source for humans. However, many species of insect pests and pathogens cause significant losses to crops. Worldwide, fruit flies (Diptera: Tephritidae) in the genera *Bactrocera, Dacus, Zeugodacus, Rhagoletis,* and *Anastrepha* are important pests of fruit trees and vegetables causing significant economic losses (White and Elson-Harris, 1994; Jesus-Barros et al., 2012; Mkiga and Mwatawala, 2015; Augustinos et al., 2019; Elghadi and Gordon, 2019; Mahmoud et al., 2020; Dominiak and Taylor-Hukins, 2022; Manrakhan, 2022). In general, the scientific literature contains a wealth of diverse information about fruit flies. However, relatively little information is available about this important pest group from Oman and the Arabian Peninsula. Within the Middle East, most published works are from Egypt, Levant, Iraq, and Iran (Saeidi et al., 2013; Mansour and Mohamad, 2016; Abd-Elgawad, 2021; Najim and Jaber, 2022), while a very low number of publications are concerned with fruit flies in the Arabian Peninsula. Of particular concern is the dearth of published information about fruit flies in Oman. Therefore, this review aims to give the reader a general updated perspective of what is known about tephritid fruit flies, and also to collate and synthesize all of the available information written about fruit flies in Oman and the Arabian Peninsula. It is hoped that this will shed light on the fauna, bio-ecology and management of tephritid fruit flies present in Oman and neighboring countries of the Arabian Peninsula.

This review contains two main sections. The first section contains a general review of the current information on tephritid fruit flies gathered from the world literature. It covers the taxonomy, morphology, and general feeding patterns of fruit flies, followed by an exhibition of the general bio-ecology of fruit flies, then by an overview of economic importance of fruit flies and the pest management methods used to control them. The second section collects all the available information on fruit flies from Oman and other countries in the Arabian Peninsula, divided into sections covering fauna, bioecology, and pest management. The literature covered in this paper was sourced mostly from the world-wide web (internet) by conducting searches using the google search engine. Thus, the gathered literature consists mostly of open access online publications. However, for Oman, the searched literature also includes printed publications by the Ministry of Agriculture, Fisheries, and Water Resources (e.g. reports and booklets), and reports on research conducted in the past by the Entomology Lab of the Department of Plant Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University. It is hoped that when more research-based publications (official and unofficial) from other countries in the Arabian Peninsula become available, a more comprehensive review of the literature about fruit flies in the region could be performed.

What are Tephritid Fruit Flies?

The Tephritidae or the true fruit flies (name used to distinguish them from the Drosophilidae, also called fruit flies, or more appropriately vinegar fruit flies) is a well-defined group of flies, which can be recognized by their moderate size, markings on the body, and patterned wings (Hill, 2008). This family can be distinguished from the similar-looking picture-winged flies (Ulidiidae Otitidae) by the right-angled bend near the end of vein Sc, just before Sc becomes faint and joins the costa, and by the frontal setae (Figure 1, White and Elson-Harris, 1994). Tephritidae is a relatively large family containing nearly 5000 species (Korneyev, 2021). According to the most agreed recent classification (Korneyev, 1999), this family is divided into six subfamilies: Dacinae (41 genera),Trypetinae (118 genera), Tephritinae (211 genera), Phytalmiinae (95 genera), Blepharoneurinae (5 genera), and Tachiniscinae (8 genera). Although these flies are known as fruit flies, not all species in this family are fruit feeders (White and Elson-Harris, 1994; Korneyev, 2021). Both Dacinae and Trypetinae are large, economically important subfamilies of more than 1,000 species each. The majority of species in both subfamilies develop in fruits. The Dacinae includes some of the most serious fruit pest species such as *Bactrocera dorsalis* (Hendel) and *Zeugodacus cucurbitae* (Coquillett). In the Trypetinae, the genera *Anastrepha* and *Rhagoletis* have several species, which are also significant pests of fruits especially in the Americas (Garcia et al., 2020).

Some species of the Trypetinae and Dacinae are known to be leaf miners or stem borers (Korneyev, 2021). The Tephritinae is the largest subfamily of Tephritidae, with about 2000 species that develop mostly in flower heads, stems and roots of Asteraceae plants, and with some species being gall formers (White and Elson-Harris, 1994; Marshal, 2012, Korneyev 2021). The Phytalmiinae (total 331 species) has species that feed in fruits or in bamboo shoots

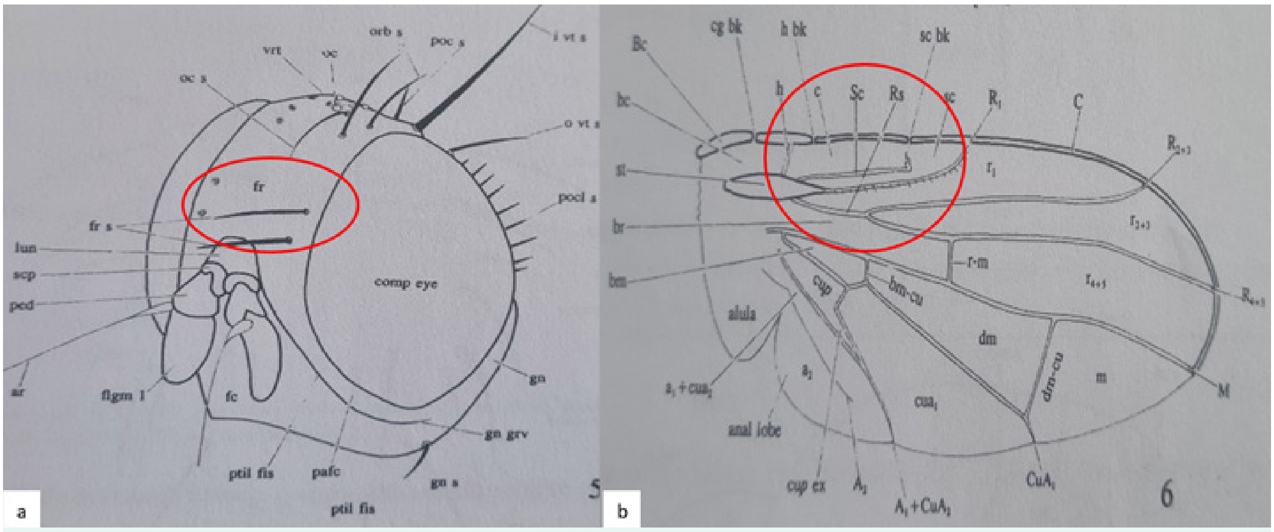


Figure 1. Distinctive characteristics of Tephritidae. a. the frontal setae (encircled) on head, b. wing venation, circled area: right-angled bend near the end of vein Sc (illustrations taken from White and Elson-Harris , 1994)

(Dohm et al. 2014: Kamiji and Matsuura 2022). The Blepharoneurinae (total 34 species) is mostly a tropical group and two genera (*Blepharoneura, Baryglossa*) are known to feed within flowers, fruits, seeds or stems of Cucurbitaceae (Norrbom and Condon, 1999). The known species of the tropical Tachiniscinae (total 18 species) are rarely encountered and poorly known (Marshal, 2012). One species from this subfamily appears to be parasitic on caterpillars and/or pupae of saturniid moths (Lepidoptera) (Korneyev and Norrbom, 2006). For differentiation between subfamilies, setae in the thorax, form of aculeus, and wing markings are used as diagnostic characters. The reader can refer to the keys provided by White and Elson-Harris (1994) and more recently by David and Ramani (2011) for distinguishing the subfamilies.

Around 100 species of fruit flies are considered economically important pest species (about 2% of all tephritid species). Most of these damage fruits of different plant families, and most of them belong in the following genera: *Bactrocera, Dacus, Ceratitis* (mostly in old world tropics and subtropics); *Anastrepha* (new world tropics and subtropics), and *Rhagoletis* (subtropics and temperate areas in new world and old world). Some tephritids are pests of seed and oil seed crops in the Asteraceae, such as safflower and sunflower. On the other hand, some tephritid species are useful as biocontrol agents, especially of weedy Asteraceae (Winston et al. 2014) by reducing their seed production capacity. For example in western parts of North America, *Urophora affinis* Frfld. and *U. quadrifasciata* Meigen have been used in the biological control of spotted knapweed (*Centaurea stoebe*), due to their ability to destroy 50-90% of seed production of this plant (Story, 2002).

Bio-ecology of Fruit Flies: Life Cycle, Host Plant Associations, and Natural Enemies

A general summary of the bio-ecology of frugivorous (i.e. fruit-feeding) fruit flies is given in the following paragraphs, with a focus on the general biology and life cycle, host plant associations, and natural enemies. For other aspects and further details about the biology, behavior, and ecology of fruit flies, the reader can refer to the work by Aluja and Norrbom (1999).

Life Cycle of Fruit Flies

The female fruit fly has a long extendible ovipositor that it uses to deposit eggs within the host fruit or between parts of the host flower in case of flower associated species (White and Elson-Harris, 1994). Eggs can be laid singly or in a cluster (Ibrahim, 2011). Duyck et al. (2007) stated that the maximum number of eggs laid per day by a female of *Bactrocera zonata* (Saunders) was 13, and the total lifetime fecundity was calculated to be 303. Fruit fly eggs are about 1 mm in size, elongated and slightly arched and usually white to creamy-yellow when first laid, becoming slightly darker towards the time of hatching (White and Elson-Harris, 1994; Deguine et al., 2015). The duration of the egg stage (embryonic stage) lasted

Table 1: Examples of economically important or potentially important fruit flies from the Dacinae, Trypetinae, and Tephritinae and their host plants

Scientific name	Common name	Host plant range	References
Bactrocera zonata	Peach fruit fly	Polyphagous	Mahmoud et al. (2020), White and Elson-Harris (1994)
Bactrocera dorsalis	Oriental fruit fly	Polyphagous	White and Elson-Harris (1994); Manrakhan(2022)
Bactrocera oleae	Olive fruit fly	*Olea europaea* (olive, wild and cultivated varieties)	White (2000)
Bactrocera tryoni	Queensland fruit fly	Polyphagous	Newman et al. (2021)
Bactrocera carambolae	Carambola fruit fly	Polyphagous	Uli., (2013)
Bactrocera cucumis	Cucumber fruit fly	Polyphagous	(Royer et al, 2014)
Bactrocera papayae	Papaya fruit fly	Polyphagous	Uli (2013)
Dacus ciliatus	Ethiopian fruit fly	Cucurbitaceae	White and Elson-Harris (1994)
Dacus longistylus	Aak fruit fly	*Calotropis procera* (Sodom's apple)	Abbaszadeh et al (2010)
Dacus persicus	Aak fruit fly	*Calotropis procera* (Sodom's apple)	Ali et al. (2020)
Dacus frontalis	Pumpkin fly	Cucurbitaceae	Elghadi and Gordon (2019)
Dacus demmerezi	Indian ocean cucurbit fly	Cucurbitaceae	White and Elson-Harris (1994)
Zeugodacus cucurbitae	Melon fly	Cucurbitaceae, also Solanaceae and other families (minor hosts)	Mkiga and Mwatawala (2015)
Ceratitis capitata	Mediterranean fruit fly	Polyphagous	Dominiak and Taylor-Hukins (2022); White and Elson-Harris (1994)
Carpomyia vesuviana	Ber fruit fly	*Ziziphus* spp	Haldhar et al. (2018); Korneyev et al. (2017)
Carpomyia incompleta	Zizphus fruit fly	*Ziziphus* spp	Abdel-Galil et al. (2014); Korneyev et al. (2017)
Rhagoletis indifferens	Western cherry fruit fly	Sweet and sour cherries, japanese plum, klamath plum	White and Elson-Harris (1994); Korneyev et al. (2017)
Anastrepha obliqua	West Indian fruit fly	Polyphagous	Jesus-Barros et al. (2012); EPPO (2023)
Anastrepha striata	Guava fruit fly	Polyphagous	Jesus-Barros et al. (2012)
Anastrepha distincta	Inga fruit fly	Polyphagous	Jesus-Barros et al. (2012); White and Elson-Harris (1994)
Anastrepha ludens	Mexican fruit fly	Polyphagous	White and Elson-Harris (1994)
Acanthiophilus helianthi	Safflower fly	Asteraceae	Merz and Dawah (2005)

between 2 and 4 days at temperatures between 15 and 35 °C for *B. dorsalis* (Dongmo et al., 2021), while for *B. zonata*, the duration was 1.5 to 10 days at the same temperature range (Duyck et al., 2004a).

Fruit flies have three larval instars, but some flower-associated species complete the first instar before emerging from the egg, so only two larval instars are apparent (White and Clement, 1987; White and Elson-Harris, 1994). After hatching, maggots associated with fruits bore into the fruit interior and feed on the pulp (Thakur and Gupta, 2016). Larvae of Dacinae and Tryptinae are usually maggot-like. The first instar larvae are extremely small and almost translucent, while the second instar larvae are creamy-white and very similar to the third instar but smaller in size (White and Elson-Harris, 1994). The total duration of the larval stages of *B. zonata* varies from 4 to 30 days at 35°C and 15°C respectively (Duyck et al., 2004a), which is similar to that of *B. dorsalis* (6-35 days) (Capinera, 2008).

Most fruit feeding larvae tend to leave the fruits and drop to the soil for pupation via their unique jumping behavior, but most flower feeding Tephritinae pupate within the host tissue (White and Elson-Harris, 1994). The white, brown, and black tephritid puparia tend to be rounded at the anterior end and rounded or flat on the posterior end (White and Elson-Harris, 1994). The duration of the pupal stage varies by species and developmental conditions, for example the pupal development of *B. zonata* took 8 and 53 days, at 35°C and 15°C respectively (Duyck et al., 2004a), while for *B. dorsalis* it took 7 and 31.5 days at 33°C and 15°C respectively (Dongmo et al., 2021).

The pre-oviposition period for *B. dorsalis* lasted 9-51 days at a temperature range of 15-33 °C, reaching its minimum between 25 and 30°C (Dongmo et al., 2021). For *B. zonata*, it lasted 8-28 days at a temperature range of 20 to 35°C (Fetoh et al., 2012). Females of *B. zonata* can live for up to 126 days (EPPO, 2023); however, in the temperature range of 20 to 35 °C, they live 31 to 107 days (Fetoh et al., 2012), while *B. dorsalis* females can live 10-180 days at temperatures ranging from 15 to 35°C. The typical life cycle of fruit flies, exemplified by *B. zonata* is shown in Figure 2.

Temperate species with a narrow host range such as *Rhagoletis* spp are usually univoltine (one generation per year). However, tropical species of *Anastrepha*, *Bactrocera*, *Ceratitis* and *Dacus* are typically multivoltine having several generations per year (White and Elson-Harris, 1994; Ibrahim, 2011). This is due to the relatively short generation turnover time for such species, e.g., *B. dorsalis* can complete

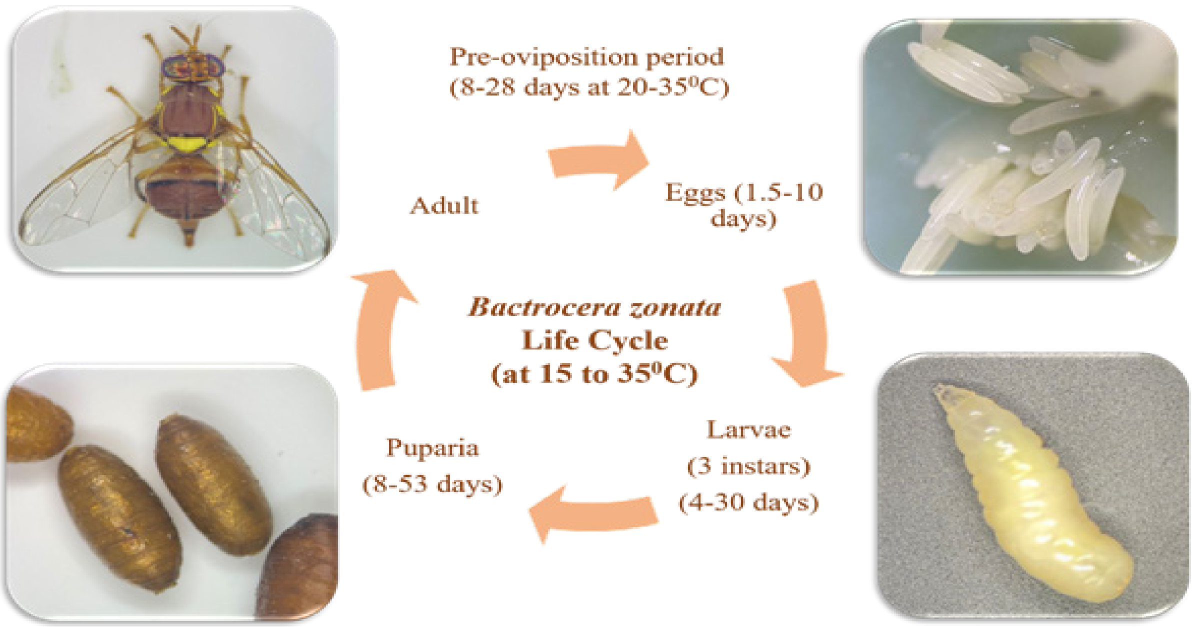


Figure 2. *Typical life cycle of fruit flies, shown here for Bactrocera zonata (durations are based on Duyck et al., 2004a and Fetoh et al., 2012; images by first author).*

a generation in about 30 days according to Capinera (2008), or as little as 24 days if the aforementioned durations for the immature stages and the pre-oviposition period, are summed together.

Host Plant Associations

Rhagoletis spp. and *Carpomyia* spp. tend to be oligophagous and restricted to a single plant genus or a few closely related plant genera (White and Elson-Harris, 1994). The same is true for *Dacus* spp. and *Zeugodacus* spp, which show a strong preference for attacking species of a single plant family (typically Apocynaceae or Cucurbitaceae) (White and Elson-Harris, 1994). However, species such as *Z. cucurbitae* also attack fruits of species in other plant families, e.g., Solanaceae, although these are minor hosts (De Meyer et al., 2015). Truly, polyphagous species belong to the genera *Anastrepha*, *Bactrocera*, and *Ceratitis* (White and Elson-Harris, 1994). Table 1 shows the most economically important fruit flies around the world and their host plants.

Natural Enemies of Fruit Flies

Tephritid fruit flies are fed on by different predatory and parasitic arthropods in addition to larger animals such as birds. They are associated with and infected by nematodes, bacteria, fungi, and viruses. An overview of the relationship between tephritid fruit flies and their natural enemies is given below.

Stibick (2004) compiled about 1077 unique world-wide combinations of different parasitoid/ predator species and the economically important fruit fly species that they feed on. An overwhelming majority of these combinations included parasitoid species, with only 32 predatory species being recorded. Parasitoids have proven to be the most useful in biological control of fruit flies in different parts of the world. The utilization of parasitoids in biological control is described in a later section.

Predators

Some species of ants, sphecid wasps, coleopteran Staphylinidae and Carabidae, neuropteran Chrysopidae, hemipteran Pentatomidae, dipteran Cecidomyiidae, species from a number of Dermaptera families, and some species of mites are known to prey on tephritid eggs, larvae, and pupae (Bateman, 1972; Stibick, 2004). Spiders have also been reported to feed on fruit flies (Eskafi and Kolbe, 1990; Galli and Rampazzo, 1996). Furthermore, birds and mice are also known to feed on fruit fly pupae (Ansari et al., 2012; Stibick, 2004). In a study of potential predators of olive fruit fly in Portugal, Ramires (2020) surveyed predatory insect and spider species on olive canopy and on the ground. Using DNA gut analysis to confirm predation on olive fruit fly, she concluded that among the many morpho-species that she found, only three of the most abundant species of ants (*Tapinoma* sp., *Plagiolepis pygmaea*, *Crematogaster scutellaris*) showed evidence of predation (by detection of olive fruit fly DNA in them). Meanwhile, none of the most abundant spider species tested positive for olive fruit fly.

Parasitoids

The below overview of parasitoids of fruit flies is mostly based on the information provided by Wharton and Yoder (2023). Eggs, larvae, and puparia of tephritid fruit flies are attacked by parasitic wasp species belonging to 10 families: Chalcididae, Eulophidae, Eupelmidae, Eurytomidae, Ormyride, Pteromalidae, Figitidae, *Bracon*idae, Ichneumonidae, and Diapriidae. The most diverse and abundant group of parasitoids attacking fruit flies is in the subfamily Opiinae within the *Bracon*idae. Around 100 species of Opiine *bracon*ids are parasitoids of tephritid fruit flies (Wharton and Yoder, 2023). Within the Opiinae, the most important fruit fly-feeding genera are: *Diachasmimorpha, Fopius, Psyttalia, and Utetes*. *Diachasmimorpha* and *Utetes* species are originally from both the New and Old Worlds, while *Fopius* and *Psyttalia* species area of origin is in the Old world (mostly Asia for *Fopius*, both Africa and Asia for *Psyttalia*). Opiinae species are koinobiont solitary endoparasitoids of cyclorrhaphan Diptera, which start parasitism in the egg or larva and emerge as adults from the puparium of their hosts. Most of the hosts are Tephritidae, Agromyzidae or Anthomyiidae. All of the aforementioned Opiinae genera have species that are larval-pupal (or larval-prepupal) parasitoids except for some *Fopius* species (e.g. F. *arisanus*) which are egg-pupal (or pre-pupal) parasitoids. Thus, females of species of *Diachasmimorpha*, *Psyttalia*, and *Utetes* seek larvae of fruit flies within fruit, while females of some *Fopius* species (e.g. F. *arisanus* (Sonan)) seek eggs laid just under the fruit skin. It is unusual for *Diachasmimorpha*, *Psyttalia*, and *Utetes* species to target larvae in fallen fruits, although Vargas et al. (2012) mentioned that *D. longicaudata* (Ashmead) may forage for fruit fly larvae on fallen fruits. In the case of co-existence of egg-pupal *Fopius* species with other Opiinae spcies (multi-parasitism), the advantage is for the *Fopius* species due to their earlier presence in the host larva, thereby preventing the development of the other species. None

Table 2. A world-wide list of parasitoid species associated with six economic fruit fly species found in Oman. The list is based on the work of Stibick (2004), with the latest valid taxonomic names extracted from the the work of Wharton and Yoder (2023). The parasitoid species are organized by taxonomic group (superfamily, family, subfamily, genus, species). All are Hymenoptera, except where indicated.

Fruit fly species	Parasitoid species	Taxonomic Group
Bactrocera dorsalis	*Diachasmimorpha albobalteata*	Ichneumonoidea: *Bracon*idae: Opiinae
	Diachasmimorpha hageni	Ichneumonoidea: *Bracon*idae: Opiinae
	Diachasmimorpha kraussii	Ichneumonoidea: *Bracon*idae: Opiinae
	Diachasmimorpha longicaudata	Ichneumonoidea: *Bracon*idae: Opiinae
	Diachasmimorpha tryoni	Ichneumonoidea: *Bracon*idae: Opiinae
	Fopius arisanus	Ichneumonoidea: *Bracon*idae: Opiinae
	Fopius deeralensis	Ichneumonoidea: *Bracon*idae: Opiinae
	Fopius persulcatus	Ichneumonoidea: *Bracon*idae: Opiinae
	Fopius skinneri	Ichneumonoidea: *Bracon*idae: Opiinae
	Fopius vandenboschi	Ichneumonoidea: *Bracon*idae: Opiinae
	Psyttalia fijiensis	Ichneumonoidea: *Bracon*idae: Opiinae
	Psyttalia fletcheri	Ichneumonoidea: *Bracon*idae: Opiinae
	Psyttalia incisi	Ichneumonoidea: *Bracon*idae: Opiinae
	Psyttalia makii	Ichneumonoidea: *Bracon*idae: Opiinae
	Utetes bianchii	Ichneumonoidea: *Bracon*idae: Opiinae
	Utetes manii	Ichneumonoidea: *Bracon*idae: Opiinae
	Dirhinus anthracina	Chalcidoidea: Chalcididae
	Dirhinus auratus	Chalcidoidea:Chalcididae
	Dirhinus giffardii	Chalcidoidea:Chalcididae
	Dirhinus himalayanus	Chalcidoidea:Chalcididae
	Tachinaephagus sp.	Chalcidoidea:Encyrtidae
	Aceratoneuromyia indica	Chalcidoidea:Eulophidae
	Aceratoneuromyia indica	Chalcidoidea:Eulophidae
	Tetrastichus giffardii	Chalcidoidea:Eulophidae
	Tetrastichus sp.	Chalcidoidea:Eulophidae
	Pachycrepoideus vindemmiae	Chalcidoidea:Pteromalidae
	Spalangia afra	Chalcidoidea:Pteromalidae
	Spalangia endius	Chalcidoidea:Pteromalidae
	Spalangia endius	Chalcidoidea:Pteromalidae
	Spalangia gemina	Chalcidoidea:Pteromalidae
	Spalangia grotiusi	Chalcidoidea:Pteromalidae
	Spalangia simplex	Chalcidoidea:Pteromalidae
	Spalangia sp.	Chalcidoidea:Pteromalidae
	Coptera silvestrii	Proctotrupoidea: Diapriidae
	Trichopria sp.	Proctotrupoidea: Diapriidae
	Coptera sp.	Proctotrupoidea: Diapriidae
	Aganaspis daci	Cynipoidea: Figitidae: Eucolinae
	Cothonaspis sp.	Cynipoidea: Figitidae: Eucolinae
	Pseudeucoila sp.	Cynipoidea: Figitidae: Eucolinae
	Trybliographa sp.	Cynipoidea: Figitidae: Eucolinae

Bactrocera zonata	*Austroopius sp.*	Ichneumonoidea: *Braconi*dae: Opiinae
	Diachasmimorpha longicaudata	Ichneumonoidea: *Braconi*dae: Opiinae
	Fopius persulcatus (?)	Ichneumonoidea: *Braconi*dae: Opiinae
	Fopius vandenboschi A	Ichneumonoidea: *Braconi*dae: Opiinae
	Opius sp.	Ichneumonoidea: *Braconi*dae: Opiinae
	Psyttalia makii	Ichneumonoidea: *Braconi*dae: Opiinae
	Psyttalia sp. nr fletcheri	Ichneumonoidea: *Braconi*dae: Opiinae
	Trybliographia daci	Cynipoidea: Figitidae: Eucolinae
Dacus ciliatus	*Diachasmimorpha brevistyli*	Ichneumonoidea: *Braconi*dae: Opiinae
	Diachasmimorpha brevistyli	Ichneumonoidea: *Braconi*dae: Opiinae
	Diachasmimorpha carinata	Ichneumonoidea: *Braconi*dae: Opiinae
	Diachasmimorpha longicaudata	Ichneumonoidea: *Braconi*dae: Opiinae
	Fopius caudatus	Ichneumonoidea: *Braconi*dae: Opiinae
	Psyttalia concolor	Ichneumonoidea: *Braconi*dae: Opiinae
	Psyttalia fletcheri	Ichneumonoidea: *Braconi*dae: Opiinae
	Psyttalia phaeostigma	Ichneumonoidea: *Braconi*dae: Opiinae
	Psyttalia incisi	Ichneumonoidea: *Braconi*dae: Opiinae
	Dirhinus himalayanus	Chalcidoidea:Chalcididae
	Spalangia afra	Chalcidoidea:Pteromalidae
	Spalangia cameroni	Chalcidoidea:Pteromalidae
	Spalangia grotiusi	Chalcidoidea:Pteromalidae
	Pachycrepoideus vindemmiae	Chalcidoidea:Pteromalidae
	Coptera sp.	Proctotrupoidea: Diapriidae
	Sarcophaga (Phytosarcophaga) destructor	Diptera: Sarcophagidae
Zeugodacus cucurbitae	*Diachasmimorpha albobalteata*	Ichneumonoidea: *Braconi*dae: Opiinae
	Diachasmimorpha dacusii	Ichneumonoidea: *Braconi*dae: Opiinae
	Diachasmimorpha fullawayi	Ichneumonoidea: *Braconi*dae: Opiinae
	Diachasmimorpha hageni	Ichneumonoidea: *Braconi*dae: Opiinae
	Diachasmimorpha longicaudata	Ichneumonoidea: *Braconi*dae: Opiinae
	Diachasmimorpha tryoni	Ichneumonoidea: *Braconi*dae: Opiinae
	Fopius arisanus	Ichneumonoidea: *Braconi*dae: Opiinae
	Fopius vandenboschi	Ichneumonoidea: *Braconi*dae: Opiinae
	Ipobracon sp.	Ichneumonoidea: *Braconi*dae: Opiinae
	Opius # 4	Ichneumonoidea: *Braconi*dae: Opiinae
	Psyttalia fletcheri	Ichneumonoidea: *Braconi*dae: Opiinae
	Psyttalia humilis	Ichneumonoidea: *Braconi*dae: Opiinae
	Psyttalia incisi	Ichneumonoidea: *Braconi*dae: Opiinae
	Utetes bianchii	Ichneumonoidea: *Braconi*dae: Opiinae
	Dirhinus anthracina	Chalcidoidea:Chalcididae
	Dirhinus auratus	Chalcidoidea:Chalcididae
	Dirhinus giffardii	Chalcidoidea:Chalcididae
	Dirhinus himalayanus	Chalcidoidea:Chalcididae
	Aceratoneuromyia indica	Chalcidoidea:Eulophidae

	Tetrastichus giffardianus	Chalcidoidea:Eulophidae
	Anagrus (Paranagrus) optabilis	Chalcidoidea:Mymaridae
	Pachycrepoideus vindemmiae	Chalcidoidea:Pteromalidae
	Spalangia afra	Chalcidoidea:Pteromalidae
	Spalangia endius	Chalcidoidea:Pteromalidae
	Spalangia nigra	Chalcidoidea:Pteromalidae
	Spalangia sp.	Chalcidoidea:Pteromalidae
	Splangia cameroni	Chalcidoidea:Pteromalidae
	Splangia hirta	Chalcidoidea:Pteromalidae
	Coptera silvestrii	Proctotrupoidea: Diapriidae
Carpomyia vesuviana	*Utetes bianchii*	Ichneumonoidea: *Bracon*idae: Opiinae
	Fopius arisanus	Ichneumonoidea: *Bracon*idae: Opiinae
	Fopius carpomyiae	Ichneumonoidea: *Bracon*idae: Opiinae
	Fopius vandenboschi	Ichneumonoidea: *Bracon*idae: Opiinae
	Psyttalia incisi	Ichneumonoidea: *Bracon*idae: Opiinae
	Psyttalia makii	Ichneumonoidea: *Bracon*idae: Opiinae
	Psyttalia nr. makii	Ichneumonoidea: *Bracon*idae: Opiinae
	Diachasmimorpha longicaudata	Ichneumonoidea: *Bracon*idae: Opiinae
	Bracon fletcheri	Ichneumonoidea: *Bracon*idae: BBbBB-*Bracon*inae
	Bracon lefroyi	Ichneumonoidea: *Bracon*idae: *Bracon*inae
	Omphale sp.	Chalcidoidea: Eulophidae
Carpomyia incompleta	*Psyttalia concolor*	Ichneumonoidea: *Bracon*idae: Opiinae
	Opius sp.	*Bracon*idae: Opiinae
	Eupelmus urozonus	Chalcidoidea:Eupelmidae
	Tetrastichus sp.	Chalcidoidea:Eulophidae

of the Opiinae species are known to act as hyperparasitoids. Some *Bracon* species (*Bracon*inae) are idiobiont ectoparasitoids of frugivorous fruit fly larvae. The female wasp paralyzes the host and the larva develops on it within the fruit, eventually spinning a cocoon and emerging as an adult from the fruit rather than from the soil as Opiine *bracon*ids do. Some ichneumonid species attack puparia of fruit flies in the soil (e.g. *Gelis* species with wingless females). In the Diapriidae, species of *Coptera* are endoparasitoids of pupae of fruit flies. Other important genera of parasitoids specialized on fruit flies are the idiobiont solitary ectoparasitic *Dirhinus* species (Chalcididae, e.g. *D. giffardi*) which parasitize pupae of fruit flies within puparia in the soil. Other pupal parasitoids include the pteromalid *Pachycrepoideus vindemmiae* (Rondani) and a number of *Spalangia* species. Additionally, species of eucoiline Figitidae, in the genera *Aganaspis* and *Odontosema*, are solitary koinobiont larval-pupal endoparasitoids of fruit flies. In the Eulophidae, several species (e.g. *Tetrastichus* spp.) are gregarious koinobiont larval-pupal endoparasitoids. Some Eupelmidae speices (e.g. *Eupelmus urozonus*) are ectoparasitic on late instar larvae and on pupae of fruit flies. They can act as hyperparasitoids of other fruit fly parasitoids. These aforementioned non-Opiinae parasitoids are less abundant and less frequently associated with fruit flies. It should be noted that many of the non-Opinnae parasitic wasps associated with larvae and pupae of fruit flies could act as hyperparasitoids of the Opinnae (Wharton and Yoder, 2023). This is especially true of the chalcidoid species. For a complete and extensive listing of all parasitic insects associated with tephritid fruit flies up to 2004, the reader is referred to the work by Stibick (2004) and for more recent but less comprehensive listing, the reader may refer to Wharton and Yoder (2023). A listing of parasitoids asscciated with the six most economic fruit fly species present in Oman (*B. dorsalis*, *B. zonata*, *Z. cucurbitae*, *Dacus ciliatus Loew*, *Carpomyia vesuviana*, *C. incompleta*) is given in Table 2. It is based on the work of Stibick (2004), but uses the latest valid taxonomic names in the work of Wharton and Yoder (2023).

Symbiotic and Entomopathogenic Microorganisms

Fruit flies are also associated with much smaller organisms, microorganisms that interact with them either positively or negatively. They include nematodes, fungi, bacteria, and viruses. The following is a brief description of what is known in terms of the interaction of these microorganisms with fruit flies. Some of the microorganism species may act as entomopathogens useful in biological control. Their use in biological control is described in a later section.

Symbiotic Microorganisms

Fruit flies contain in their guts different species of Enterobacteriacae (e.g. *Klebsiella, Citrobacter, Enterobacter, Providencia, Erwinia, Proteus, Serratia*) as dominant bacteria fauna (Akami et al., 2019; Raza et al., 2020). These bacteria play an important role for host fruit flies in terms of increasing longevity and fecundity, protection from pathogenic microorganisms, detoxification of toxic compounds in their diets or in pesticides, and provisioning of essential amino acids missing in the diet (Akami et al., 2019; Raza et al., 2020). Akami et al. (2019) reported that *B. dorsalis* adults, free of gut bacteria (axenic), consistently selected diets inoculated with bacteria and they responded faster to diets with bacteria than the diet lacking bacteria and consumed more of the former. This indicates the ability of fruit flies, while foraging in the field, to choose foods that contain these essential gut bacteria, thus enhancing their fecundity and longevity. In addition to the above intercellular bacteria, *Wolbachia* spp. exist in different fruit fly species intracellularly. *Wolbacha* infection has the potential to cause cytoplasmic incompatibility which makes matings between males and females infertile, leading to population collapse and thus could serve as a pest management tool (incompatible insect technique IIT) similar to the sterile insect technique (SIT) for fruit fly management (Gichuhi et al., 2019; Wang et al., 2019).

Entomopathogenic Microorganisms

Some microorganisms are pathogenic to different stages of fruit flies. These include fungi, nematodes and bacteria. Fungi pathogenic to fruit flies belong in the Cordycipitaceae (e.g. the genera *Beauveria, Lecanicillium=Verticilium, Isaria*) and Clavicipitaceae (e.g. the genus Metarhizium) (Shaurub, 2022). Blastospores or conidia of entomopathogenic fungi (EPFs) usually germinate on host cuticle to form germ tubes that penetrate the cuticle. The penetration is affected mechanically by hyphal growth and chemically by enzymes (proteases, peptidases, chitinases, and lipases). Once the host is penetrated, hyphae grow extensively in its hemocoel leading to death of the host. Then blastospores or conidia are produced which restart the infection in new healthy hosts (Sharma and Sharma, 2021; Shaurub, 2022). Secondary metabolites of EPFs, including destruxins, are toxic to fruit flies, and may play an important role in the mode of action of EPFs. Additionally, at sub-lethal doses, EPFs could affect the fecundity of female fruit flies (Shaurub, 2022). Generally, larvae and adults of fruit flies are more susceptible to infection by entomopathogenic fungi than fully formed puparia. The most susceptible are newly emerged young adults. The heavily sclerotized exoskeleton of the puparium cannot be penetrated as readily by the germ tubes, while the less sclerotized cuticle of the larval and adult allows penetration (Shaurub, 2022). The hairy body of the adults allows more conidia to adhere, thereby increasing the chance of infection in adults (Shaurub, 2022). For further aspects of the interaction between entomopathogenic fungi and fruit flies (environmental factors, secondary metabolites, effects on fruit fly reproduction, etc.), the reader is referred to the work of Shaurub (2022).

More than 90 species of steinernematids and heterorhabditids have been described (Shapiro-Ilan et al., 2014). Certain soil-borne nematodes in the genera *Steinernema* (Steinernematidae) and *Heterorhabditis* (Heterorhabditidae) are obligate pathogens, which are associated symbiotically with bacteria in the genera *Xenorhabdus* and *Photorhabdus* (Shaurub, 2022). The description of the life cycle of these entomopathogneic nematodes (EPNs) was described by Tofangsazi et al. (2008) and Shaurub (2022). The infective stage of these nematodes are called infective juveniles (IJs) which are free living and disperse in search of new hosts. They enter the host via openings in its body (e.g. mouth, anus, spiracles) or through the cuticle. After entering into the host, they release their bacteria symbionts, which grow and proliferate within the host, thereby providing nutrition to the nematodes. The growth of these bacteria and the toxins they produce lead to the death of the host within 48 hours. Nematodes complete 2–3 generations within the host, after which IJs are produced. Then, IJs exit the dead host to search for new hosts. In addition to dispersal, and host finding, IJs allow entomopathogenic nematodes the ability to survive difficult and extreme conditions (Shaurub, 2022). As in the case of entomopathogenic fungi, the most vulnerable stages of fruit flies are larvae entering the soil, young puparia, as well as emerging adults. Larvae are more vulnerable to infection by EPNs compared to puparia because they are active and they release CO2, and thereby can be sensed more easily by IJs (Shaurub, 2022). The exoskeleton of larvae is also less sclerotized and has larger openings when compared to puparia. The reader is referred to the review by Shaurub (2022) for further details about the biology and interaction between entomopathogenic nematodes and their fruit fly hosts (e.g. abiotic and biotic environmental factors, dispersal, reproduction in host, and compatibility with fruit fly parasitoids).

Little information is available about bacteria pathogenic to fruit flies. Salas et al. (2017) found that *Morganella morganii* (Enterobacteriaceae) is an extremely lethal pathogen of mass reared Mexican fruit flies, capable of causing 100% mortality in larvae reared on artificial diet. Qessaoui et al. (2022) demonstrated in a laboratory study that strains of *Pseudomonas* sp. (a rhizobacterium) collected from soil around tomato plants in Morocco were pathogenic against pupae and adults of *Ceratitis capitata* (Wiedemann). On the other hand, RNA viruses have been shown to be associated with different fruit flies (e.g. Queensland fruit fly virus) (Sharpe et al., 2021; Zhang et al., 2022). In a study by Moussa (1978 in Sharpe et al., 2021), injection of this virus in *Bactrocera tryoni* (Froggatt) adults led to 92% mortality after four week. The virus appeared to have effects on the digestive system causing symptoms such as swollen midgut.

Economic Importance and Management of Frugivorous Fruit Flies

Economic Importance

The direct damage of frugivorous fruit flies is due to oviposition wounds and larval feeding inside fruits. Bacteria and fungi may enter egg-laying holes causing the fruits to deteriorate rapidly and to fall prematurely (Clarke et al., 2011). This makes fruits unsuitable for consumption due to the pre- and post-harvest spoilage (Kamala-Jayanthi et al., 2012).

Fruit flies can also cause economic losses to the growers by loss of export markets due to strict quarantine regulations related to fruit fly infestations (Thakur and Gupta, 2016). The impact on fresh fruit and vegetable trading can be because of embargos, loss of markets, quarantine regulations, and subsequent job losses (Papadopoulos, 2014). Due to the economic importance of the damaged fruits and vegetables, quarantine regulations have been set up to manage the spread and threat of fruit flies internationally and locally (Papadopoulos, 2014).

In India, Sharma et al. (2011) mentioned that *B. dorsalis* caused 100.0, 87.0, 78.0 and 61.0% fruit damage on guava, mango, peach and pear, respectively. In Africa, *Ceratitis cosyra* (Walker) caused

10-100% damage in mango production (Lux et al., 2003). In Réunion, fruit flies caused huge losses to vegetables, reaching 60–90 % in untreated fields (Ryckewaert et al., 2010). Furthermore, in Pakistan, *B. zonata* caused 50-55% infestation in guava fruits (Chauhan et al., 2011).

Annual fruit losses in the Mediterranean region countries due to the activity of only *C.capitata* were estimated to be about U.S. $365 million if no control measures are applied (Enkerlin and Mumford, 1997). In Egypt, damage due to *B. zonata* is estimated to be EUR 190 million per year (EPPO, 2005). Moreover, about US$35 million have been used to eradicate occurrences of *C. capitata* (Wiedemann) in Florida since 1997–1998 (Hallman and Loaharanu, 2002). The potential economic losses in China due to *B. zonata* (in case of introduction) could reach 0.82–3.07 billion dollars per year (Qin et al., 2021)

Management of Fruit Flies

For management of fruit flies many tactics have been used worldwide, including chemical control (e.g. insecticides), physical control (e.g. fruit bagging), and biological control (e.g. SIT).Although insecticides have been the mainstay of fruit fly management for several decades in the past, the non-target nature of insecticides, residue restrictions, resistance build-up and negative environmental and health impacts demands the search for alternative control methods (Calvitti et al., 2002). Thus, in addition to chemical control, these alternative control methods are discussed below.

Chemical Control

Fruit flies are difficult to control by insecticides since the eggs and maggots are inside the fruits while pupae develop within the soil out of reach of insecticides, so the management tactics should be targeting the adult stage (Kotikal and Math, 2017). Additionally, the use of systemic insecticides may produce residues in fruits creating a health hazard (Craddock et al., 2019). Synthetic contact insecticides have been used for control of fruit fly adults, for example, *C. capitata* control programs have long been carried out using organophosphates and pyrethroids (Benelli et al., 2012). Insecticides have been applied in the form of insecticidal cover sprays and insecticidal bait (i.e. a mixture of attractive protein-based material mixed with insecticide) spot applications (Dominiak, 2018). Quarantine restrictions can be imposed to limit further spread of fruit fly pests (White and Elson Harris, 1994). In quarantine settings, fumigation with methyl bromide and other compounds is used as part of phytosanitary regulations before fruits are cleared for export (Hossain et al., 2011).

Plants produce secondary plant metabolites, which play a role in the defense mechanism against herbivores (Ilyas et al., 2017). Such compounds can be used as alternatives to synthetic insecticides for safe and environmentally friendly management. These bioactive botanical compounds can have insecticidal, growth-regulating, or repellent effects (Ilyas et al., 2017). For example, Benelli et al. (2012) reported that the essential oils from *Lavandula angustifolia* Miller, *Hyptis suaveolens L*, and *Thuja occidentalis L* were toxic (at a concentration of 0.25 mL/fly) by contact against *C. capitata* adults under laboratory conditions, causing mortality rates of 100%, 96.7%, 96.7% respectively. Plant extracts can also be used as repellent and oviposition deterrents for fruit flies. Thakur and Gupta (2016) reported that the mean egg laying and egg hatchability of *Zeugodacus tau* (Walker) decreased with increased test concentrations of neem oil (from *Azadirachta indica*). Ilyas et al. (2017) reported that the highest repellency (84.14%) against *B. zonata* was due to an extract of *Datura alba* (=*D. metel* L.), while the highest oviposition inhibition (57.14%) was produced by an extract of neem. Also, Hidayat et al. (2013) reported that plant oils (safflower, cottonseed, linseed and neem oil) had higher repellency against *Bactrocera tryoni* than essential oils (lemon-scented gum, lemon-scented ironbark, narrow-leaved peppermint, broad-leaved peppermint, lemon-scented tea tree, peppermint, honey myrtle and lemon).

Plants produce phytochemicals in the form of volatiles, which act as attractants for insect pests (Jaleel et al., 2018). Plant kairomones (host and non-host plant species), parapheromones, food-based lures, and sex pheromones are examples of olfactory attractants for fruit flies (Alagarmalai et al, 2009). Lures consisting of food odor attractants or parapheromones have a long history of practical use for population monitoring and control of tephritid fruit flies via trapping of adult fruit flies or attracting them to baits laced with insecticides (Economopoulos, 2002). Para-pheromone lures help in the detection of species and population size, but these are designed to attract only male fruit flies (Jaleel et al., 2018). The most important male lures are methyl eugenol, cue lure, trimed lure, terpinyl acetate and vert lure (White and Elson-Harris, 1994). Methyl eugenol attracts a number of *Bactrocera* species (e.g. *B. dorsalis* and *B. zonata*) and some *Ceratitis* spp. in the subgenus *Pardalaspis* (White and Elson-Harris, 1994; Dominiak, 2018). Cue lure attracts *Dacus* spp. and *Zeugodacus* species (e.g., *D. demmerezi* and *Z. cucurbitae*, Deguine et al., 2015), and it also attracts *Bactrocera* species. Surprisingly more *Bactrocera* species than *Dacus* species are attracted to cue lure according to data from White and Elson-Harris (1994). Trimedlure attracts many *Ceratitis* spp. in the subgenera *Ceratitis* and *Pterandrus*, including the Med fly, *C. capitata* (White and Elson-Harris, 1994; Alagarmalai et al., 2009). There are also protein-based food lures like Nulure, Buminal, Ceratrap, and torula yeast that mostly capture females searching for protein sources that are needed for sexual maturation and egg development (Hagen and Finney, 1950; Duyck et al., 2004b, Lasa et al., 2015). There are also ammonia-producing lures such as Biolure that have been tested for their attractiveness to fruit flies (e.g. Cornelius et al., 2000).

Trapping using lures can be considered a form of control that uses a chemical (usually a parapheromone, food-based lure such as torula yeast, or an ammonia-based lure) and a trapping container to prevent physical escape of the captured fruit fly. Additionally, the water in liquid-based lures (e.g. torula yeast) acts as a physical killing agent through drowning of the fruit flies that fall into the liquid (AlSaadi, 2022). If lure is used dry (without water), then a suitable insecticide is added to ensure that entering flies are killed before escaping from traps (Hill, 2008).The male annihilation technique (MAT) depletes the males from the population to break the reproductive cycle by using a large number of traps, containing an effective lure (e.g. methyl eugenol), placed over a large area (Dominiak and Nicol, 2012; Singh and Sharma, 2013). MAT has been successfully applied worldwide against *Bactrocera* species (Jaleel et al., 2018), for example, it successfully eradicated the oriental fruit fly, *B. dorsalis* in Rota Island (Northern Mariana Islands) in the Pacific Ocean (Steiner et al., 1965a)

Physical-mechanical control

Tephritid fruit flies are attracted to colors and shapes that are similar to host fruit and foliage (Economopoulos, 2002). For example, *Bactrocera* species respond to orange, yellow, and green colors (Jaleel et al., 2018). Yellow color (in combination with lure) is relatively more effective for trapping of these species (Wee et al., 2018). However, the yellow color has a drawback because it also attracts many other insect species, including beneficial parasitoids (Economopoulos, 2002). Physically based management of fruit flies may include fruit bagging where large fruits can be individually wrapped in paper or fabric before reaching the suitable stage for fruit fly attack (White and Elson-Harris, 1994). These physical barriers protect the fruits by preventing female flies from laying eggs. This technique has been widely used to protect mangoes in Thailand and Philippines and melons from melon fly in Taiwan (Ansari et al., 2012).

Field sanitation can also be effective in controlling fruit flies. Fallen and infested fruits should be removed from the field and destroyed to prevent pupation in the soil. This can break the cycle and reduce fruit flies population. Ansari et al. (2012) reported that if field sanitation is practiced at community scale it could be very useful method for reducing fruit fly population and it is the most effective method in melon fly management. For quarantine purposes, exported fruits may be treated with radiation, cold temperatures, or hot water. Generally, irradiation and hot water treatments are the most acceptable and commonly practiced phytosanitary treatments used in fruit-related quarantine regulations (Sarwar, 2015; Jaleel et al., 2018).

Biological Control of Fruit Flies

Biological Control using Parasitic Wasps

Historically, biological control of fruit flies were practiced via the classical strategy, which involves introductions of exotic parasitic wasps as part of one or more projects or programs. More recently, there has been much more emphasis on the augmentative strategy through continuous releases of parasitic wasps reared in mass. Also, a shift to conservation and enhancement of native or already established parasitoids via reduction of use of pesticides, growing of plants which support the feeding and sheltering by these natural enemies, and provisioning of augmentoriums, which are tent like structures that block any fruit flies emerging from infested fruits, while allowing the parasitoid wasps to pass through their fine mesh walls.

Classical Biological Control Method

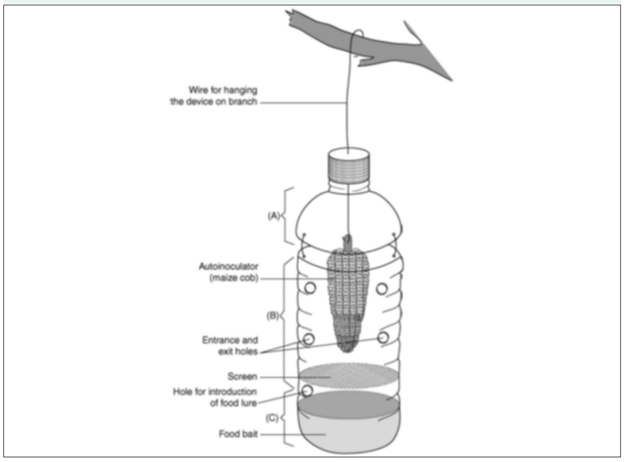
Biological control of Tephritidae began early in the 20th century (around 1912) in Hawaii against *Z. cucurbitae* (introduced there in 1895) through the release of 8 species of parasitic wasps including the larval-pupal parasitoid *Psyttalia fletcheri* Silvestri (*Bracon*idae) and six predatory arthropods (Vargas et al., 2012; Deguine et al., 2015). The parasitic *P. fletcheri* contributed to the reduction in damage of cucurbit crops in Hawaii (Vargas et al., 2012). This was followed by a very large classical control program to manage the then newly introduced *B. dorsalis* and *C. capitata*, which involved introductions of 32 species of natural enemies in the period from 1947 to 1952. Two of the best performing *bracon*id parasitoids during this period were *Diachasmimorpha longicaudata* and *Fopius arisanus*, both of which were introduced from Asia. *Diachasmimorpha longicaudata* was released first in 1948, and it became the dominant parasitoid recovered from field fruit fly puparia. However, it was soon superseded from 1950 onwards by F. *arisanus* (released in 1950), an egg-pupal parasitoid. A high percentage (65%-70%) of *B. dorsalis* puparia produced F. *arisanus* adults (Bess et al., 1961; Vargas et al., 2012). Since that time, improvements in rearing techniques has allowed the rearing of F. *arisanus* in large numbers for classical biological control programs in Pacific island nations such as French Polynesia, Fiji, and Northern Mariana Islands as well as in Australia (Vargas et al., 2012). These introductions were started as early as 1951. Similar classical biological control programs of fruit flies were attempted starting in 1955 in other areas of the world (e.g. Florida, Central America, Reunion and Mauritius islands in the Indian Ocean) and were initiated by direct or indirect importation of the most effective biological control agents (*D. longicaudata*, F. *arisanus*, *P. fletcheri*) from Hawaii (Vargas et al., 2012; Garcia et al., 2020). More recently (starting in 2006), F. *arisanus* and *D. longicaudata* were introduced from Hawaii to target *B. dorsalis* in several African countries (Ekesi et al., 2016).

Augmentative Biological Control Method

The first attempt at mass rearing and periodic releases of parasitoids of fruit flies was practiced in Hawaii. This experience gave the mixed results of increases in parasitism rates in the field, but little impact on damage of targeted crops (Vargas et al., 2012). Augmentative biological control of fruit flies has also been practiced in Mexico and Guatemala in Central America, as well as Brazil and Argentina in South America, mostly utilizing *D. longicaudata* to target *Anastrepha* spp. and *C. capitata* (Garcia et al., 2020). More recently, there has been a move toward mass rearing and releasing parasitoids native to Central and South America (Garcia et al., 2020).

Figure 3 *Augmentorium design used in Hawaii. Infested fruits are placed inside this tent-like structure. The mesh at the top of the augmentorium allows emerged parasitoids to escape, while preventing the fruit flies from leaving to re-infest more fruits. Source: Ricciuti (2022)*

Figure 4. *Example of auto-dissemination device which can be used to distribute entomopathogenic fungi and chemosterilants using male lure or food bait. Source: Dimbi et al., 2003 (in Shaurub, 2022).*



Conservation Biological Control Method

Work on conservation of fruit fly parasitoids has involved the use of augmentoriums, plant refuges or alternate non-crop hosts, and planting of nectar-rich plants. The augmentorium (Fig. 3) is a tent like structure in which fallen infested fruits are kept. The fine mesh of the walls of the tent allows the smaller parasitic wasps, which emerge from fruits, to leave the augmentorium but prevents fruit flies from escaping to cause more damage. The idea apparently started in Hawaii in the early 2000s (Klungness et al., 2005).

More recently, it was experimented with in Kenya (Ekesi and Billah, 2007), Reunion Island (Deguine et al., 2011), Australia (Harris et al., 2022), and France (Desurmont et al., 2022). In all four countries, the augmentoriums proved effective, with authors of the studies recommending its use on a wider scale. Work on planting nectar-rich plants in farm landscapes and plants acting as alternate non-crop hosts gave mixed results in Australia (Harris et al., 2022). Although the wild tobacco, *Solanum mauritianum* Scop., and its wild tobacco fly (*Bactrocera cacuminata* (Hering)) acted as good reservoir for F. *arisanus* when fruit crops were not available, tests of flowers and fruits of different plants as food resources did not produce any significant increase in longevity of the parasitoid (Harris et al., 2022).The authors of this study recommended the conservation of wild tobacco and its companion fruit fly as alternate hosts for F. *arisanus* in Australia, but did not recommend the intentional planting of nectar-providing plants.

Biological Control using Entomopathogenic Fungi (EPFs)

A variety of mycoinsecticides (171 products) has been developed in the period between 1967 and 2007 (De Faria and Wraight, 2007). The most common four species in terms of % prevalence as products (utilized as different strains) are: *Beauveria bassiana* (Bals.-Criv.) Vuill. (33.9%), *Metarhizium anisopliae* (=M. robertsii (Metchnikoff) Sorokin) (33.9%), Isaria fumosorosea Wize =(*Paecilomyces fumosoroseus*) (5.8%), and *Beavueria brongniartii* (Saccardo) (4.1%). De Faria and Wraight (2007) published a useful listing of these products giving the species (and varieties under species), trade name, formulation, type of propagule, country(ies) of registration, pests registered for, and manufacturer. The most common propagules was conidia, and the most common formulation was fungus-colonized substrates (e.g. cereal grains) containing a mix of sporulating mycelia and spores (26.3%), followed by wettable powders (20.5%), and oil dispersions (15.2%). All of the four aforementioned species generate asexual spores (conidia) which can be produced relatively easily. However, the list provided by De Faria and Wraight (2007) is outdated now (in terms of which products are currently registered or available, manufacturer details, etc.) and lacks information related to strains of each fungus species. Strains of entomopathogenic fungi (EPF) species used in biological control determine the temperature, humidity, and soil characteristics at which the species can be effective (Shaurub, 2022). Other than these factors, exposure to light (UV), and antagonistic or synergetic activity of microbiota within the soil (including predation by unicellular organisms, small arthropods (mites, Collembola), competition by other fungi), and mortality of fruit fly natural enemies (parasitoids and predators) due to the applied EPFs may impact the effectiveness, utility and practicality of EPFs in fruit fly control (Shaurub, 2022). The application methods of EPFs may include aerial spraying (cover sprays), bait sprays (spot application), soil application (e.g. drenching) or autoinoculative device (Fig. 4) (Shaurub, 2022). It should be noted here that application of EPFs to adults (e.g. via autoinoculative device) may negatively impact mating between male and female fruit flies due to effects on male behavior (e.g. grooming to remove the adhering conidia) (Shaurub, 2022).

Biological Control using Entomopathogenic Nematodes (EPNs)

Biological control also includes the use of entomopathogenic nematodes (EPNs) to control the larvae of fruit flies in the soil. The genera *Heterorhabditis* and *Steinernema* are the only EPNs for which the mass production methods have been developed and they are the only ones sold commercially for biocontrol purposes (Sirjani et al., 2009). Although there does not appear to be any significant difference in mortality caused by *Heterorhabditis* and *Steinernema*, mean mortality caused by *Heterorhabditis* is slightly higher (67.7%, range 30-98.8%) than *Steinernema* (67.1%, range 14-92.4%) based on data tabulated by Shaurub (2022). This could be partially due to the presence of the buccal tooth found in *Heterorhabditis* but not in *Steinernema*. This structure may allow the former an extra route for penetration through larval or new pupal cuticle in addition to entry via natural openings of the host shared with *Steinernema*. Most of the commercial formulations include S. *feltiae* (Filipjev), *S. carpocapsae* (Weiser), and *H. bacteriophora* Poinar. Because of the lack of a true dormant stage (e.g. blastospores, conidia), formulations containing EPNs require conditions to ensure survival and viability of the nematodes by limiting their movement and oxygen consumption in order to induce a sort of dormancy via the anyhydrobiotic state (Cruz-Martinez et al., 2017). These formulations include cadavers of secondary host infected with EPNs, aqueous suspensions, synthetic sponges, encapsulation in alginate gel material (e.g. calcium alginate), and encapsulation in granules made from materials such as clay, wheat flour-meal, starch, and cellulose. Aqueous solutions have limited storage capacity and need refrigeration, while sponges need a system to extract the nematodes from them before application. The most promising formulations that serve the dual purpose of long storage period without loss in viability of the nematodes plus practicality of releasing the nematodes directly in the field, without need for an intermediate step of extraction, are the encapsulated formulations mentioned above (Martinez et al., 2017). Infected cadavers formulation may contain materials such as kaolin and starch to conserve the cadavers until they are applied. Application of EPNs can be done via conventional spraying equipment (with big openings in nozzles and without filters) (Tofangsazi et al., 2018), or application of infected cadavers to the soil using specialized delivery systems (Martinez et al., 2017). Application of EPNs can be directed not only to the soil under and around the crop, but also to infested fruits. For example, *Steinernema feltiae* were successfully used against larvae of *B. zonata* inside guava fruits (Mahmoud et al., 2016) and against *B. olea* (Rossi) larvae within fallen olive fruits (Sirjani et al., 2009).

Biological Control using Entomopathogenic Bacteria

Although some experiments indicated substantial mortality due to *B. thuringiensis* and other *Bacillus* species (Karamanlidou et al., 1991; Ruiu et al., 2015), these experiments utilized fruit fly larvae fed on diet laced with the bacteria. In the field, it can be impractical to expose fruit fly larvae to these bacteria because they feed hidden within fruits. This means that until now there is no technique to practically utilize *Bacillus* bacteria in management of fruit flies.

Sterile Insect Technique

The sterile insect technique (SIT) involves releasing millions of sterile male flies into the wild population in order for the wild females to have a strong likelihood to mate with the sterile males. Such matings would be infertile leading to ultimate crash in the population (Deguine et al., 2015). This technique is implemented by rearing fruit flies in large numbers, sterilizing males by ionizing radiation or chemical means, and then releasing the sterile males into the environment (Deguine et al., 2015). It is environmentally safe and insect-specific and with no negative effects on non-target insect pests (Pereira et al., 2013). The SIT method was applied successfully against different fruit fly species in different countries. For example, in Rota Island in the Western Pacific and in various islands of Japan, SIT was successfully used to eradicate *Z. cucurbitae* (Steiner et al., 1965b; Klassen et al., 2021). Also the Mediterranean fruit fly has been either suppressed or eradicated by use of SIT in several regions of the world including California and Florida (Klassen et al., 2021). Despite the passage of about 50 years since SIT was first applied for the management of fruit flies, this method is not fully adapted universally for all pestiferous fruit fly species and in all countries highly affected by these pests. This is probably due to the relatively high costs of setting up of facilities and of maintenance of the program relative to other methods. Additionally, SIT is not that effective when pest populations are high as this would result in low ratio of the released sterile males vs. the wild fertile males in the field (Navarro-Llopis et al., 2011). This necessitates integrating SIT with other methods of control for effective management of pest fruit flies. For further insights about the use of SIT for fruit fly management, the reader is referred to the work by Dyck et al. (2021).

Other Sterility-Causing Methods

Recently, potentially more economic yet effective methods, to introduce sterility in populations of pestiferous fruit fly species, have been investigated. These methods include use of chemosterilants in auto-dissemination devices. Experiments using chemosterilants on fruit flies started as laboratory studies on the olive fruit fly in the late 1970's (Fytizas, 1976 in Casana-Giner et al., 1999) and the Mediterranean fruit fly in the early 1980's (Sarasua et al., 1983 in Casana-Giner et al., 1999). Casana-Giner et al. (1999) tested the effect of 10 IGR (insect growth regulator) compounds (admixed in adult diet) on the egg hatchability, fecundity, pupation, and adult emergence of *C. capitata*. They concluded that lufenuron produced the greatest decreases (100%) in egg hatch and pupation followed by triflumuron. Effect on adult emergence by lufenuron was not tested due to zero pupae produced, and fecundity values for this compound were not declared by authors. A series of follow-up field-based studies were carried out by Navarro-Llopis et al. (2004, 2007, 2010, 2011) using lufenuron as chemosterilant against *C. capitata*. A proteinacous gel, containing lufenuron, was used as bait in addition to male and female lures, all placed in delta trap in addition to other trap designs. Results indicated lower fruit fly populations (Navarro-Llopis et al., 2007, 2010) in plots with the lufenuron treatment in comparison to conventional malathion treated plots and lower damage to persimmon (Navarro-Llopis et al., 2010) in lufenuron treated plots. Lower damage to persimmon, citrus, and stone fruits was detected when lufenuron was used in combination with

SIT than when SIT was used alone (Navarro-Llopis et al., 2011). More recently, lab-based research by Li et al (2022) showed that of four chemicals tested on Z. *tau*, hxamethylphosphoramide (HMPA) was the most effective sterilizing agent based on measure of fecundity of females and egg hatchability. The study by Hasnain et al. (2023) on *B. zonata* confirmed earlier results by Casana-Giner et al. (1999) in terms of high efficacy of lufenuron as a chemosterilant of fruit flies. Hasnain et al. (2023) tested the effect of six concentrations of five IGR compounds (pyriproxyfen, novaluron, lufenuron, buprofezin, flubendiamideon) on the fecundity, egg hatching, and malformation on puparia and adults of *B. zonata* in a lab setting. This was done by feeding the adults on diet laced with each of the aforementioned compounds. Hasnain et al. (2023) found that at the highest dose, lufenuron produced low levels of fecundity (31.1%) and egg hatchability (19.8%) that were significantly different from the control. It also caused evident malformation in adults and puparia. The length, diameter and weight of puparia in the lufenuron treatment was significantly lower than in the control. These results were similarly produced, but to a lesser extent, by the other tested compounds pyriproxyfen, novaluron, buprofezin, and flubendiamide (in order of decreasing effect). It has to be noted here that the use of auto-dissemination devices for distributing chemosterilants (or entomopathogenic fungi, see above) to individuals of the target fruit fly species, carries the risk of negatively affecting non-target insects (particularly species of other flies). This is especially true in the case of using a general food-based or ammonia-based lure and not a lure specific to the target fruit fly species.

Other more novel technologies for producing some form of sterility in tephritid fruit flies include RNA interference and use of *Wolbachia*. RNA interference can target genes controlling male sterility. This can be accomplished by gene silencing using double-stranded RNA (dsRNA). General applications for this technology would involve silencing of essential genes to interfere with development and reproduction of fruit flies or by making fruit flies more susceptible to insecticides (Maktura et al., 2021). On the other hand, *Wolbachia* infection can be used in the incompatible insect technique (IIT) by producing cytoplasmic incompatibility in male fruit flies. Such infected males, if released in the wild, may mate with *Wolbachia* free females or females infected with a different and incompatible *Wolbachia* strain leading to infertile matings (Mateos et al., 2020). These two types of futuristic technologies are still in their infancy and although they have promising potential, there are no proven and demonstrated applications related to pest management of fruit flies. For further information about RNA interference and *Wolbachia* -fruit fly related research, the reader is referred to Maktura et al. (2021) and Mateos et al. (2020) respectively.

Fauna of Fruit Flies of Oman and the Arabian Peninsula

Fruit flies of Oman

In 1981, a study was conducted by the Ministry of Agriculture to manage *Dacus cucurbitae* Coquillett on watermelon (MAF, 1980-1981). This was probably a misidentification of *Dacus ciliatus Loew*, the more common species infesting cucurbits in Oman. In a booklet on citrus cultivation published by the Ministry of Agriculture and Fisheries (Khan et al., 1983), a number of pests were mentioned but these did not include any fruit fly species. In a listing of insects and mites from Oman (MAF, 1992), *Carpomyia incompleta* (Becker) was recorded from Nizwa in 1977 on *Ziziphus*. *Dacus* (*Bactrocera*) *dorsalis* Hendel (=*Bactrocera dorsalis* (Hendel)) was recorded in 1980 in a light trap in Rumais Research Station (MAF, 1992). In 1984, *Dacus* (*Bactrocera*) *dorsalis* was recorded on mango fruits from Qurayyat (MAF, 1992). Both of these reports involved a misidentification of *B. zonata* (Saunders), as no *B. dorsalis* was detected in Oman by AlWahaibi et al. (2006), based on a survey running from 2003 to 2005. A guide published by the Ministry of Agriculture and Fisheries (MAF, 1989) mentioned *Ziziphus* fruit fly (*Carpomyia incompleta*) as a severe pest of *Ziziphus* fruit (ber) which could cause the loss of the whole harvest. Later, *D. dorsalis* (=*B. dorsalis*) was reported in citrus, mango, guava, sweet melon and watermelon (MAF, 1994), another probable misidentification of *B. zonata*. The latter two host plants probably were incorrect for either *B. dorsalis* or *B. zonata*. In the same report *Dacus* sp. was recorded on cucurbits

Furthermore, Merz (2002) recorded two fruit fly species (as new records), which were *Goniurellia ebejeri* Merz from Muscat (Al Ansab) and *Goniurellia octoradiata* Merz from Dhofar (Hagayf). Azam et al. (2004) recorded five fruit fly species, among them *Carpomyia vesuviana* Costa as a new species to Oman, in addition to *C. incompleta*, *B. zonata*, *D. ciliatus*, and *D. longistylus* Wiedemann. Al Wahaibi et al. (2006) reported six species: *B. zonata*, *D. ciliatus*, *D. longistylus*, and *Dacus nr. mulgens*, a new species to Oman on the milkwee Gomphocarpus

Table3. A listing of the species of tephritid fruif flies recorded in Oman, other countries in the Arabian Peninsula, and Iran. The list of species is organized by subfamily and then by genus within subfamily. Also included are the larval host plant, larval plant part, and pest status (as per available information), as well as additional information (under "Notes"). Sources of data: **Oman**: Merz (2002, 2011), Azam et al. (2004), AlWahaibi et al. (2006), AlAnsari (2009), MAF (2015), AlJabri (2017). MAFWR (2020a), Unpublused data (second author of this paper); **Yemen**: Merz et al. (2006); **Saudi Arabia**: Merz and Dawah (2005); **United Arab Emirates (UAE)**: De Meyer and Freidberg (2005), Merz (2008, 2011), Namin and Roberts (2020); **Qatar, Bahrain**: no species recorded in available literature; **Kuwait**: Amr (2021)

						Country Presence								
Serial #	**Subfamily**	**Species**	**Host plant**	**Plant part**	**Pest Status**	**Oman**	**Yemen**	**Saudi Arabia**	**UAE**	**Qatar**	**Bahrain**	**Kuwait**	**Iran**	**Notes**
1	Dacinae	*Bactrocera zonata*	Polyphagous	Fruit	**Pest**	**X**	**X**	**X**	**X**				**X**	
2		*Bactrocera dorsalis*	Polyphagous	Fruit	**Pest**	**X**			**X**				**X?**	
3		*Bactrocera olea*	*Olea eruropea* (cutlivated and wild)	Fruit	**Pest**	**X**		**X**				**X**	**X**	
4		*Bactrocera musae*	Polyphagous?	Fruit	**Pest**	**X?**								
5		*Bactrocera latifrons*	Polyphagous?	Fruit	**Pest**								**X?**	
6		*Zeugodacus cucurbitae*	Cucurbitaceae (possibly on other plants such as Solanaceae)	Fruit	**Pest**	**X**		**X**	**X**				**X?**	
7		*Dacus ciliatus*	Cucurbitaceae	Fruit	**Pest**	**X**	**X**	**X**	**X**				**X**	
8		*Dacus persicus*	*Calotropis procera* (Apocynaceae)	Fruit	Not pest	**X**			**X**				**X**	
9		*Dacus (Leptoxyda) longistylus*	*Calotropis procera* (Apocynaceae)	Fruit	Not pest		**X**	**X**	**X?**					
10		*Dacus (Leptoxyda) annulatus*	*Asclepias curssavica* (Apocynaceae)	Stem	**Potential pest**		**X**	**X**						
11		*Dacus (Didacus) sp. nr. arcuatus*	Unknown (possibly *Pergularia daemia*)	Fruit	Not pest			**X**						
12		*Dacus (Leptoxyda) semisphaereus*	Possibly Apocynaceae?	Possibly fruit?	?			**X**	**X**					
13		*Dacus (Didacus) vertebratus*	Cucurbitaceae	Fruit	**Pest**		**X**	**X**	**X**					
14		*Dacus (Leptoxyda) obesus*	*Calotropis procera* (Apocynaceae)	Fruit	Not pest			**X**						
15		*Dacus (Didacus) nr. mulgens*	*Gomphocarpus fruticosus*	Fruit	Not pest	**X**								
16		*Dacus frontalis*	Cucurbitaceae	Fruit	**Pest**	**X?**	**X**	**X**						
17		*Dacus punctatifrons*	Cucurbitaceae, Solanaceae,	fruit	**Pest**		**X**							
18		*Dacus chamun*	(Apocynaceae)?	Fruit?	?		**X**							
19		*Dacus sp. aff. rufus*	*Fockea multiflora* (Apocynaceae)		Not pest		**X**							
20		*Dacus sp. 1*	?	?	?		**X**							***wing pattern similar to Z. cucurbitae***
21		*Dacus sp. 2*	?	?	?			**X**						
						Country Presence								
Serial #	**Subfamily**	**Species**	**Host plant**	**Plant part**	**Pest Status**	**Oman**	**Yemen**	**Saudi Arabia**	**UAE**	**Qatar**	**Bahrain**	**Kuwait**	**Iran**	**Notes**
22		*Capparimyia savastani*	*Capparis* species (Capparaceae)	Flower bud (rarely fruits)	**Potential pest on *Capparis spinosa***	**X**	**X**		**X**				**X**	
23		*Capparimyia aenigma*	*Maerua* spp. , *Boscia* spp. Capparaceae	Flower bud, fruit	**Potential pest on *Capparis***			**X**						
24		*Neoceratitis efflatouni*	*Lycium schweinfurthii = L.*	*Fruit?*	Not pest	**X**		**X**	**X**					
25		*Neoceratitis flavoscutellata*	*?*	*?*	?			**X**						
26		*Ceratitis capitata*	Polyphagous	Fruit	**Pest**		**X**	**X**				**X**	**X**	
27		*Ceratitis quinaria*	Polyphagous	Fruit	**Pest**		**X**							
28		*Ceratitis sp. aff. aliena*	*Solanum nigrum* (Solanaceae)	Fruit	**Potential pest**		**X**							
29		*Trirhithrum sp. aff. occipitale*	*Cissus* spp, *Cyphostemma*	Fruit	**Potential pest**		**X**							
30	Trypetinae	*Carpomyia incompleta*	*Ziziphus* spp. (Rhamnaceae)	Fruit	**Pest**	**X**		**X**	**X**					
31		*Carpomyia vesuviana*	*Ziziphus* spp. (Rhamnaceae)	Fruit	**Pest**	**X**			**X**				**X**	
32		*Myiopardalis pardalina*	Cucurbitaceae	Fruit	**Pest**			**X**					**X**	
33		*Rhagoletis berberidis*	Berberidaceae	Fruit	**Pest**								**X**	
34		*Rhagoletis cerasi*	Polyphagous	Fruit	**Pest**								**X**	
35		*Rhagoletis flavicincta*	Caprifoliaceae	Fruit	**Pest**								**X**	
36		*Rhagoletis flavigenualis*	Juniperus	?	?								**X**	
37		*Rhagoletis sp.*	Unknown (possibly *Juniperus*		Not pest	**X**								
38		*Anastrepha striata*	?	?	?								**X?**	
39		*Chetostoma curvinerve*	in galls on *Lonicera* induced by some sawflies	galls	?								**X**	
40		*Euleia heraclei*	Apiaceae-as leaf	leaf	?								**X**	
41		*Euleia kovalevi*	Apiaceae-as leaf	leaf?	?								**X**	
42		*Philophylla caesio*	Polyphagous -as leaf		?								**X**	
43	Tephritinae	*Goniurellia ebejeri*	Asteraceae?	Flower?	Not pest	**X**								
44		*Goniurellia octoradiata*	Asteraceae?	Flower?	Not pest	**X**			**X**					
45		*Goniurellia tridens*	Asteraceae?	Flower?	Not pest	**X?**		**X**	**X**				**X**	***Oman: Based on observaton by scientist from UAE who visited northern Oman***

						Country Presence								
Serial #	Subfamily	Species	Host plant	Plant part	Pest Status	Oman	Yemen	Saudi Arabia	UAE	Qatar	Bahrain	Kuwait	Iran	Notes
46		*Goniurellia persignata*	*Pulicaria arabica* (Asteraceae)	Flower	Not pest			**X**					**X**	
47		*Goniurellia spinifera*	Pulicaria desertorum (Asteraceae)	Flower	Not pest		**X**	**X**						
48		*Goniurellia lacerata*	Asteraceae?	Flower?	?				**X**				**X**	
49		*Goniurellia apicalis*	Asteraceae?	Flower?	?		**X**							
50		*Goniurellia longicauda*	Asteraceae?	Flower?	?				**X**				**X**	
51		*Goniurellia sp.*	Asteraceae?	Flower?	?		**X**							
52		*Oxyaciura tibialis*	*Lavandula* spp., *Nepeta septemcrenata* (Lamiaceae)		**Potential pest**	**X**		**X**	**X**				**X**	
53		*Oxyaciura nigra*	?	?	?				**X**					
54		*Ensina sonchi*	Asteraceae	Flower	**Potential pest**			**X**					**X**	
55		*Bactropota sp. 1*	Asteraceae	?	?			**X**						
56		*Rhochmopterum arcoides*	*Vernonia kraussii* (Asteraceae)	Flower?	Not pest			**X**						
57		*Rhochmopterum sp.*	?	?	?		**X**		**X**					
58		*Schistopterum moebiusi*	*Pluchea dioscoridis* (Asteraceae)	Flower?	Not pest		**X**	**X**	**X**				**X**	
59		*Psednometopum cf. aldabrense*	?	?	?			**X**						
60		*Psednometopum aldabrense*	?	?	?		**X**							
61		*Stephanotrypeta brevicosta*	?	?	?			**X**						
62		*Stephanotrypeta vittata*	?	?	?		**X**	**X**						
63		*Dicheniotes angulicornis*	?	?	?		**X**	**X**						
64		*Dicheniotes multipunctatus*	?	?	?			**X**						
65		*Dicheniotes sp.*	?	?	?		**X**							
66		*Gymnaciura austeni*	?	?	?		**X**	**X**						
67		Unidentified species (genus nr.	?	?	Not pest	**X**								***black wings, yellow***

						Country Presence								
Serial #	Subfamily	Species	Host plant	Plant part	Pest Status	Oman	Yemen	Saudi Arabia	UAE	Qatar	Bahrain	Kuwait	Iran	Notes
73		*Paraspheniscoides binarius*	*Lippia* spp., *Lantana* spp. (Verbenaceae)	?	**Potential pest, weed biocontrol**		**X**	**X**						
74		*Paraspheniscus debskii*	*Stachys aegyptiaca* (Lamiaceae)	Flower?	?			**X**						
75		*Acanthiophilus helianthi*	Asteraceae	Flower	**Pest**			**X**	**X**			**X**	**X**	
76		*Arabodesis reductiseta sp. n.*	?	?	?			**X**						
77		*Campiglossa ignobilis*	*Sonchus oleraceus* (Asteraceae)	Flower	?		**X**	**X**						
78		*Capitites augur*	*Pulicaria crispa* (Asteraceae)	Flower	?			**X**				**X**		
79		*Dectodesis auguralis*	?	?	?		**X**	**X**						
80		*Dectodesis sp. 1*	?	?	?			**X**						
81		*Dectodesis sp. 2*	?	?	?		**X**							
82		*Desmella sp. nr myiopitoides*	*Chrysocoma tenuifolia* (Asteraceae)	flower?	?			**X**						
83		*Dioxyna sororcula*	Asteraceae	flower, Seed	**Pest**		**X**	**X**						
84		*Euarestella iphionae*	?	?	?			**X**					**X?**	
85		*Euarestella korneyevi*	?	?	?				**X**					
86		*Euarestella sp. near kugleri*	?	?	?				**X**					
87		*Euarestella vanharteni*	?	?	?				**X**					
88		*Freidbergia mirabilis*	*Pluchea* spp.	flower?	Not pest			**X**						
89		*Hyalotephritis complanata*	*Pluchea dioscoridis* (Asteraceae)	flower?	Not pest			**X**						
90		*Hyalotephritis planiscutellata*	*Pluchea dioscoridis* (Asteraceae)	flower?	Not pest		**X**	**X**	**X**					
91		*Spathulina acroleuca*	Mexican sunflower, other Asteraceae	Flower	**Potential pest**		**X**	**X**						
92		*Sphenella marginata*	*Senecio* spp.	flower?				**X**					**X**	
93		*Sphenella setosa sp. n.*	?	?	?	**?**		**X**						
94		*Tanaica maculata sp. n.*	?	?	?	**?**		**X**						
95		*Tanaica pollinosa sp. n.*	*Tripteris auriculata* (Asteraceae).	flower?	Not pest			**X**						
96		*Telaletes ochraceus*	?	?	?			**X**						
97		*Tephritomyia despoliata*	possibly *Echinops* spp. (Asteraceae)	?	?			**X**					**X**	
98		*Trupanea amoena*	Marigold, other Asteraceae	flower	**Pest**			**X**	**X**			**X**	**X**	

						Country Presence								
Serial #	**Subfamily**	**Species**	**Host plant**	**Plant part**	**Pest Status**	**Oman**	**Yemen**	**Saudi Arabia**	**UAE**	**Qatar**	**Bahrain**	**Kuwait**	**Iran**	**Notes**
99		*Trupanea pseudoamoena*	*Pulicaria crispa* (Asteraceae) (	flower?	?			**X**						
100		*Trupanea pulcherrima*	*Launaea nudicaulis* (Asteraceae)	flower?	?			**X**	**X**				**X**	
101		*Trupanea repleta*	?	?	?		**X**	**X**						
102		*Trupanea stellata*	Marigold, other Asteraceae	Flower	**Potential pest**			**X**	**X**			**X**	**X**	
103		*Trupanea ornum*	?	?	?		**X**							
104		*Trupanea sp. 1*	?	?	?			**X**						
105		*Trupanodesis sp. 1*	possibly *Vernonia* (Asteraceae)	?	?			**X**						
106		*Genus nr. Trupanodesis sp. 1*	?	?	?		**X**							
107		*Genus nr. Trupanodesis sp. 2*	?	?	?		**X**							
108		Unidentified sp.	Unidentified		Not pest	**X**								***spotted wing***
109		*Aciura afghana*	?	?	?				**X**				**X**	
110		*Aciura coryli*	Lamiaceae	Flower	**Potential pest**								**X?**	
111		*Katonaia aida*	*Leucas inflata*	?	?				**X**					
112		*Sphaeniscus trifasciatus*	?	?	?	**X**			**X**					***Oman: collected in Jabal AlAkhdhar by Gallagher in 1991 (possibly the species with M in wing)***
113		*Sphaeniscus sexmaculatus*	?	?	?		**X**							
114		*Trupanea tubulata*	?	?	?				**X**					
115		*Elaphromyia pterocallaeformis*	?	?	?		**X**							
116		*Hyaloctoides semiater*	?	?	?		**X**							
117		*Hyaloctoides sokotrensis*	?	?	?		**X**							
118		*Platomma nigrantior*	?	?	?		**X**							
119		*Ocnerioxyna sp.*	?	?	?		**X**							
120		*Tephraciura semiangusta*	?	?	?		**X**							
121		*Tephraciura sphenoptera*	?	?	?		**X**							
122		*Lethyna sp.*	?	?	?		**X**							
123		*Scedella dissoluta*	?	?	?		**X**							
124		*Melanopterella sp.*	?	?	?		**X**							
125		*Genus nr. Microtreta sp. 1*	?	?	?		**X**							
126		*Hendrella kermanensis*	?	?	?								**X**	
127		*Oedaspis ragdai*	?	?	?								**X**	
128		*Eurasimona stigma*	?	?	?								**X**	
129		*Inuromaesa maura*	?	?	?								**X**	
130		*Myopites flavovarius*	?	?	?								**X**	
						Country Presence								
Serial #	**Subfamily**	**Species**	**Host plant**	**Plant part**	**Pest Status**	**Oman**	**Yemen**	**Saudi Arabia**	**UAE**	**Qatar**	**Bahrain**	**Kuwait**	**Iran**	**Notes**
131		*Myopites inulaedyssentericae*	?	?	?								**X**	
132		*Urophora affinis*	?	?	?								**X**	
133		*Urophora anthropovi*	?	?	?								**X**	
134		*Urophora aprica*	?	?	?								**X**	
135		*Urophora bakhtiari*	?	?	?								**X**	
136		*Urophora cuspidata*	?	?	?								**X**	
137		*Urophora dirlbeki*	?	?	?								**X**	
138		*Urophora doganlari*	?	?	?								**X**	
139		*Urophora impicta*	?	?	?								**X**	
140		*Urophora jaceana*	?	?	?								**X**	
141		*Urophora kasachstanica*	?	?	?								**X**	
142		*Urophora longicauda*	?	?	?								**X**	
143		*Urophora mauritanica*	?	?	?								**X**	
144		*Urophora melanocera*	?	?	?								**X**	
145		*Urophora merzi*	?	?	?								**X**	
146		*Urophora pauperata*	?	?	?								**X**	
147		*Urophora phaeocera*	?	?	?								**X**	
148		*Urophora quadrifasciata quadrifasciata*	?	?	?								**X**	
149		*Urophora quadrifasciata sjumorum*	?	?	?								**X**	
150		*Urophora repeteki*	?	?	?								**X**	
151		*Urophora sirunaseva*	?	?	?								**X**	
152		*Urophora solstitialis*	?	?	?								**X**	
153		*Urophora spatiosa*	?	?	?								**X**	
154		*Urophora stalker*	?	?	?								**X**	
155		*Urophora stylata*	?	?	?								**X**	
156		*Urophora tenuior*	?	?	?								**X**	
157		*Urophora tenuis*	?	?	?								**X**	
158		*Urophora terebrans*	?	?	?								**X**	
159		*Urophora variabilis*	?	?	?								**X**	
160		*Urophora vera*	?	?	?								**X**	
161		*Urophora xanthippe*	?	?	?								**X**	
162		*Hypenidium oculatum*	?	?	?								**X**	
163		*Hypenidium roborowskii*	?	?	?								**X**	
164		*Noeeta pupillata*	?	?	?								**X**	
165		*Acinia biflexa*	?	?	?								**X**	
166		*Actinoptera discoidea*	?	?	?								**X**	
167		*Campiglossa absinthii*	?	?	?								**X**	
168		*Campiglossa difficilis*	?	?	?								**X**	
169		*Campiglossa grandinata*	?	?	?								**X**	
170		*Campiglossa loewiana*	?	?	?								**X**	

						Country Presence								
Serial #	Subfamily	Species	Host plant	Plant part	Pest Status	Oman	Yemen	Saudi Arabia	UAE	Qatar	Bahrain	Kuwait	Iran	Notes
171		*Campiglossa misella*	Chrysanthemums, other Asteraceae?	Flower	**Potential pest**								**X**	
172		*Campiglossa producta*	?	?	?								**X**	
173		*Capitites ramulosa*	?	?	?								**X**	
174		*Dioxyna bidentis*	?	?	?								**X**	
175		*Euaresta bullans*	?	?	?								**X**	
176		*Heringina arezoana*	?	?	?								**X**	
177		*Heringina guttata*	?	?	?								**X**	
178		*Oxyna flavipennis*	?	?	?								**X**	
179		*Oxyna nebulosa*	?	?	?								**X**	
180		*[Oxyna obesa*	?	?	?								**X?**	
181		*Tephritis acanthiophilopsis*	?	?	?								**X**	
182		*Tephritis admissa*	?	?	?								**X**	
183		*Tephritis alamutensis*	?	?	?								**X**	
184		*Tephritis angulatofasciata*	?	?	?								**X**	
185		*Tephritis arsenii*	?	?	?								**X**	
186		*Tephritis azari*	?	?	?								**X**	
187		*Tephritis bardanae*	?	?	?								**X**	
188		*Tephritis brachyura*	?	?	?								**X?**	
189		*Tephritis cameo*	?	?	?								**X**	
190		*Tephritis cometa*	?	?	?								**X**	
191		*Tephritis dioscurea*	?	?	?								**X**	
192		*Tephritis divisa*	?	?	?								**X**	
193		*Tephritis erdemlii*	?	?	?								**X**	
194		*Tephritis formosa*	?	?	?								**X**	
195		*Tephritis gharalii*	?	?	?								**X**	
196		*Tephritis hendeliana*	?	?	?								**X**	
197		*Tephritis hurvitzi*	?	?	?								**X**	
198		*Tephritis hyoscyami*	?	?	?								**X**	
199		*Tephritis kogardtauica*	?	?	?								**X**	
200		*[Tephritis maccus*	?	?	?								**X?**	
201		*Tephritis matricariae*	?	?	?								**X**	
202		*Tephritis mesopotamica*	?	?	?								**X**	
203		*Tephritis multiguttata*	?	?	?								**X**	
204		*[Tephritis nigricauda*	?	?	?								**X?**	
205		*Tephritis nozarii*	?	?	?								**X**	
206		*Tephritis oedipus*	?	?	?								**X**	
207		*Tephritis pallescens*	?	?	?								**X**	
208		*Tephritis postica*	?	?	?								**X**	
209		*Tephritis praecox*	?	?	?								**X**	
210		*Tephritis pulchra*	?	?	?								**X**	
211		*Tephritis robusta*	?	?	?								**X**	
212		*Tephritis sahandi*	?	?	?								**X**	
213		*Tephritis tridentata*	?	?	?								**X**	
214		*Tephritis urelliosomima*	?	?	?								**X**	
215		*Tephritomyia lauta*	?	?	?								**X**	
216		*Trupanea richteri*	?	?	?								**X**	
217		*Chaetorellia australis*	?	?	?								**X**	
218		*Chaetorellia carthami*	Safflower, other Asteraceae?	flower	**Pest**								**X**	
219		*Chaetorellia conjuncta*	?	?	?								**X**	
220		*Chaetorellia isais*	?	?	?								**X**	
221		*Chaetorellia jaceae*	?	?	?								**X**	
222		*Chaetorellia succinea*	?	?	?								**X**	
223		*Chaetostomella cylindrica*	?	?	?								**X**	
224		*Orellia falcata*	Meadow salsify	Stem base, roots									**X**	
225		*Orellia stictica*	?	?	?								**X**	
226		*Terellia babaki*	?	?	?								**X**	
227		*Terellia barughii*	?	?	?								**X**	
228		*Terellia colon*	?	?	?								**X**	
229		*Terellia ermolenkoi*	?	?	?								**X**	
230		*Terellia freidbergi*	?	?	?								**X**	
231		*Terellia fuscicornis*	Globe artichoke	Flower bud	**Pest**								**X**	
232		*Terellia gynaecochroma*	?	?	?								**X**	
233		*Terellia korneyevorum*	?	?	?								**X**	
234		*Terellia longicauda*	?	?	?								**X?**	
235		*Terellia luteola*	Safflower, other Asteraceae?	Flower	**Pest**								**X**	
236		*Terellia nigripalpis*	?	?	?								**X**	
237		*Terellia nigronota*	?	?	?								**X**	
238		*Terellia odontolophi*	?	?	?								**X**	
239		*Terellia orheana*	?	?	?								**X**	
240		*Terellia plagiata*	?	?	?								**X**	
241		*Terellia pseudovirens*	?	?	?								**X**	
242		*Terellia quadratula*	?	?	?								**X**	
243		*Terellia ruficauda*	?	?	?								**X**	
244		*Terellia serratulae*	?	?	?								**X**	
245		*Terellia tristicta*	?	?	?								**X**	
246		*Terellia tussilaginis*	?	?	?								**X**	
247		*Terellia uncinata*	?	?	?								**X**	
248		*Terellia virens*	?	?	?								**X?**	
249		*Terellia virpana*	?	?	?								**X**	
250		*Terellia whitei*	?	?	?								**X**	
251		*Terellia zerovae*	?	?	?								**X**	
252		*Valera ariana*	?	?	?								**X**	
253		*Xyphosia miliaria*	?	?	?								**X**	
254	Unidentified family	Unidentified sp.	?	?	?	**X**								***with M pattern in wing***

Table 4. Names (scientific, common); adult diagnostic characteristics and images; host plants, parasitoids, general world distribution, and distribution records in Oman for the six most economic fruit fly species found in Oman.
*Sources of data: White and Elson-Harris (1994), Plant Health Australia (2018), AlWahaibi et al. (2006), AlWahaibi (unpublished data), AlAnsari (2009), MAF (2015), MAFWR (2020b).

Fruit fly Species scientific name	Common names	Adult Diagnostic characteristics (including images)	Host plants in Oman	Associated Parasitoids in Oman	World Distribution	Distribution in Oman
Bactrocera zonata (Saunders)	Peach Fruit Fly, Peach-Guava Fruit Fly	6 mm long, predominantly pale orange-brown to red-brown, scutum with 2 lateral yellow stripes (vittae) and with facial spots , reduced wing pattern (spot near wing apex). Abdominal terga III-V red-brown with a 'T' pattern consisting of a narrow transverse black band in tergum III, and a narrow medial longitudinal black line often found only in terga IV and V. 	mango, guava, *Ziziphus*, Indian almond, banana, Sapodilla, fig, , *Citrus* spp., Assyrian plum, peach, *Ziziphus* hajarensis banana, mango, lambag, pomegranate	*Braconi*dae (mostly reddish-orange in color): *Opius sp.* (on different host plants); , *Fopius vandenboschi, Fopius persulcatus, Psyttalia concolor, Diachasmimorpha longicaudata* (on *Ziziphus*, not confirmed could be on *Carpomyia* spp. only) Eucoilinae (Figitidae): black colored species. Collected from Dhofar (on *Ziziphus*, guava)	Original distribution: south to southeastern Asia. Current distribution: Asia; Oman, Saudi Arabia, United Arab Emirates, Yemen, Iran and other countries in Asia. Africa: Egypt, Libya, Mauritius, Reunion and Sudan. Temporary occurrence: USA, New Zealand, Europe (Austria, France, Netherlands, Slovenia)	All governorates except Al Wusta
Bactrocera dorsalis (Hendel)	Oriental Fruit Fly	Darker and larger than *B. zonata*, mostly black scutum with 2 lateral yellow stripes (vittae), facial spots, a narrow medial longitudinal black band over terga III to V linking with dark transverse narrow band in tergum III to create a T-shape, wing with a narrow dark costal band after cells bc and continuing to around apex of wing 	Data under publication	**None recorded**	Original distribution: south to southeastern Asia. Current distribution: Africa: Eastern Africa, Angola, Sudan, Cameroon, Congo, Benin; Asia: China, Pakistan, Indonesia, India Oman, UAE: Oceania: Christmas Island, Papua New Guinea, Palau, Hawaii, and Tahiti. Temporary: European countries: Austria, Belgium, France, Italy, Netherlands, and Slovenia	**Data under publication**
Scientific name	**Common names**	**Adult Diagnostic characterisitc (including images)**	**Host plants in Oman**	**Associated Parasitoids in Oman**	**World Distribution**	**Distribution in Oman**
Dacus ciliatus Loew	Ethiopian fruit fly, Lesser Pumpkin Fly	A little smaller than *B. zonata*. Predominantly orange species with facial spots, thorax without lateral yellow stripes (vittae), thorax with relatively narrow notopleural calli; wing with a dark costal band that extends around wing apex to form a prominent apical spot; abdomen tergum III often with two prominent dark spots, and in male with a pecten (comb of setae) 	bottle gourd, bitter gourd, loofah, zucchini, ash gourd colocynth (*Citrullus colocynthis*), , muskmelon, cucumber, squash, *Corallocarpus epigaeus*	**None recorded**	Original distribution: Africa and southwest Arabia; Current distribution: Middle East (Israel. Iran, Saudi-Arabia, UAE, Yemen, Oman); south Asia (Pakistan and India), Mauritius and Reunion	All governorates except Al Wusta

Zeugodacus cucurbitae Coquillett	Melon Fly	Relatively large (as large or larger than *B. dorsalis*), scutum red-brown with or without dark markings, thorax with 3 stripes (2 lateral, 1 medial); wing with a broad dark costal band expanding into a dark large prominent spot at wing apex, a broad dark anal streak, dark area along dm-cu crossvein, abdominal terga III-V orange-brown, with a narrow transverse black band across anterior margin of tergum III, with a narrow medial longitudinal dark band over terga III to V, producing T shape with transverse band 	Squash, bitter gourd; other cucurbit hosts (data under publication)	**None recorded**	Original distribution: tropical and subtropical parts of South, South East, and East Asia; Current distribution: Middle East: Oman, UAE, Saudi Arabia; Africa: countries in East and West Africa, Egypt, Mauritius, Reunion; Oceania: Hawaiian Islands	**Data under publication**
Scientific name	**Common names**	**Adult Diagnostic characterisitc (including images)**	**Host plants in Oman**	**Associated Parasitoids in Oman**	**World Distribution**	**Distribution in Oman**
Carpomyia vesuviana Costa	Ber Fruif Fly	Smaller than other species listed, but slightly larger than *C. incompleta*, with general light brown-orange color. Thorax with 13 spots arranged in U shape laterally and in posterior part. Wing with two large bands: one close to the center and almost linear, the other close to wing apex, curved with an inverted "U" shape 	*Ziziphus spina-christi, Ziziphus jujube, Ziziphus mauritiana*	*Bracon*idae (mostly reddish-orange in color): *Opius* sp. (on different host plants); *Fopius vandenboschi, Fopius persulcatus, Psyttalia concolor* (associated with *C. incompleta*, but probably also on this species), *Diachasmimorpha longicaudata* (not confirmed could be on *B. zonata* only)	Oman, UAE, India, Pakistan, Iran, Bangladesh, China and other parts of temperate Asia,- Turkey, Georgia, Turkmenistan, Uzbekistan, southerm Europe, Mauritius, other Indian Ocean islands. Has a more eastern distribution relative to *C. incompleta* (Asia as Center).	Muscat, AlBatinah South, AlBatinah North, Musandam, Assharqiyyeh North, Assharqiyyeh South, Addakhiliyyeh
Carpomyia incompleta (Becker)	*Ziziphus* Fruit Fly	Smallest among species listed, with general orange color. Thorax greyish-ornage in color, lacks spotted pattern found in *C. vesuviana*; instead it has a number of faint longitudinal lines; wing banding faint, with the central and apical bands linear and narrow. 	*Ziziphus spina-christi, Ziziphus jujube, Ziziphus mauritiana*	*Bracon*idae (mostly reddish-orange in color): *Opius* sp. (on different host plants); *Fopius vandenboschi, Fopius persulcatus, Psyttalia concolor, Diachasmimorpha longicaudata* (not confirmed could be on *B. zonata or C. vesuviana* only)	Oman, Saudi Arabia, UAE, Yemen, Sudan, Burkina Faso, Egypt, Eritrea, Ethiopia, Morocco, Iraq, Israel, Kenya, Libya, Niger,. southern Europe: France, Spain, Italy. Has more western distribution relative to *C. vesuviana* (Africa as center)	Addakhilyyeh, Muscat, AlBatinah South, AlBatinah North, Dhofar, Musandam, Assharqiyyeh South, AdDahirah

fruticosus, as well as C. *vesuviana*, *C. incompleta*. *Bactrocera oleae* (Rossi) was reported by AlAnsari (2009) on *Olea europea* (olive) in Jabal AlAkhdhar. Merz (2011) reported the presence of *Sphaeniscus trifasciatus* Korneyev & J. Dirlbek in Oman based on a male specimen collected in Jabal AlAkhdhar at 1900m. The Ministry of Agriculture and Fisheries (MAF, 2015) reported *C. incompleta*, *B. zonata*, *Bactrocera dorsalis*, *D. ciliatus*, *Dacus frontalis* Becker and *Bactrocera* musae (Tryon) based on a survey conducted in Dhofar (Salalah and Taqah). The latter species record is doubtful due to possible misidentification arising from similarity of this species to *B. dorsalis*. The record of *D. frontalis* needs verification due to strong similarity to *D. ciliatus*. The Oman Natural History Museum (ONHM) had in total five fruit fly species in its collection as of 2017: *B. zonata*, *D. longistylus*, *D. ciliatus*, *C. incompleta*, and *Neoceratitis efflatouni* (Hendel) (AlJabri, 2017). In a follow-up survey to the 2015 survey described above, an unknown species with intermediate characteristics between *B. papayae* and *B. dorsalis* was reported from ME traps hung in different locations in Salalah and Taqah (MAF, 2018). As *B. papayae* is now considered a variant of *B. dorsalis* (Schutze et al., 2014), this intermediate species is probably a variant of *B. dorsalis*. In the latest report by the Ministry of Agriculture, Fisheries, and Water Resources (MAFWR, 2020a), a total of 9 species were listed as present in Oman: *C. incompleta*, C. *vesuviana*, *B. zonata*, *B. dorsalis*, B. *cucurbitae* (Coquillett) = (*Zeugodacus cucurbitae* (Coquillett)), *B. musae*, *D. ciliatus*, *D. frontalis*, and *D. longistylus*. The above mentioned records for *D. longistylus* (Azam et al., 2004; AlWahaibi et al., 2006; Al Jabri, 2017; MAFWR, 2020a) need verification due to the evident morphological similarity to *D. persicus*, and the sharing of the same host, *Calotropis procera*.

Based on the above information, the total number of fruit fly species previously recorded from the Sultanate of Oman is 15 (or 13 species if *B. musae* and *D. frontalis* are considered erroneous identifications. In addition to the above species mentioned in the literature, we here confirm the presence of *Capparimyia savastani* (Martelli) in Oman, despite the error in the literature that it was already recorded in Oman, although it was actually recorded previously in Trucial Oman (current United Arab Emirates (UAE), see section below on Fruit Flies of UAE). Data related to the distribution of this species in Oman are expected to be published in a separate paper. Five other species have been collected by the second author (unpublished data) from mountainous areas of Oman. These species await identification. Thus, the total fauna of fruit fly species from Oman may include at least 20 species. With more extensive sampling in different ecosystems in the country, possibly more species will be discovered. All of the known tephritid fruit fly species from Oman are listed in Table 3. As can be seen, the recorded fruit flies belong to the Dacinae (11 species), Trypetinae (3 species), and Tephritinae (7 species). Ten of these (i.e 50%) are considered major pests, minor pests, or potential pests. Table 4 gives information about the economically important species of fruit flies in Oman in terms of their diagnostic characteristics, host plants, associated natural enemies, and distribution.

As can be seen from the above overview, four of the most pestiferous fruit flies in Oman (*B. zonata*, *B. dorsalis*, *Z. cucurbitae*, and C. *vesuviana*) are probably invasive species that were recently introduced to the country (in the last 40 to 45 years) due to human activity or possibly weather-related factors (e.g. storms). These four species's area of origin is the south and eastern parts of Asia (Table 4), and there is no record of them in Oman prior to 1970. Anecdotal and casual observations support the lack of infestation of fruits in fruit orchards in Oman prior to that time. It can be inferred from above overview of the fruit fly fauna of Oman that *B. zonata* entered the country around 1980, and that C. *vesuviana* was probably absent from Oman before 1990. On the other hand, the latest introductions were probably *B. dorsalis* and *Z. cucurbitae*, which probably entered the country in the period between 2000 and 2010. The fifth important pest species is the afrotropical *D. ciliatus* , which is probably the oldest introduction, possibly entering the country in the 1970's or even before, or it could be native and became a pest after the expansion of the cultivation of cucurbits in Oman starting in the 1970's.

Fruit Flies of Other Arabian Peninsula Countries

Fruit Flies of Yemen

Merz et al. (2006) reported on the fauna of fruit flies in Yemen based on the literature up to 2003 and on collections made in the periods 1990-1994 and 1997-2003 using light traps, malaise traps, and plant samples at altitudes ranging from 20 to 2400m. These authors recorded a total of 51 species from Yemen. Only 15 of the species were Dacinae, while 36 species belonged in the Tephritinae. They considered eight of the species to have pest status, and all these pest species belonged in the Dacinae. A full list of fruit fly species recorded from Yemen is provided in Table 3.

Fruit Flies of the United Arab Emirates (UAE)

De Meyer and Freidberg (2005) recorded *C. savastani* from Trucial Oman (currently UAE) based on a collection by M. Baily from Sir Abu Nair (Abu Dhabi) in 1963. Namin and Roberts (2020) reported a total of 34 species of tephritid fruit flies from the United Arab Emirates, including their own recording of *C. savastani* as a species new to the UAE (despite the fact it was already recorded by De Meyer and Freidberg, 2005), probably due to mistaking Trucial Oman with the modern Sultanate of Oman, in addition to records found in earlier research work (van Harten, 2005; White 2006; Merz, 2008, 2011). Most of these collections were made using malaise and light traps. The recorded species were 10 species from the Dacinae, 2 species from the Trypetinae, and 22 species from the Tephretinae. The authors did not comment on the pest status of any of the species. However, Merz (2008) mentioned that six of the tephritid species recorded from the UAE were considered to be pests. Merz (2008, 2011) included illustrations (line drawings and photos) of the different fruit fly species that he listed. A full list of fruit fly species recorded from the UAE is given in Table 3.

Fruit Flies of Saudi Arabia

According to Merz and Dawah (2005), 62 species of tephritid fruit flies were recorded from Saudi Arabia in the subfamilies Dacinae (16 species), Trypetinae (2 species), and Tephritinae (44 species). Ten of these species were considered to be pest species. Forty of the species were newly collected from Aseer using malaise traps at sites situated between 260 and 2200 m above sea level. The remaining 22 species from Aseer were listed by the authors as previously recorded species from different parts of Saudi Arabia. Nine species of tephritids (*Dacus frontalis, B. zonata, D. vertebratus, Ensina sonchi, Capitites augur, Acanthiophilus helianthi, Dioxyna sororcula, Goniurellia tridens, Trupanea stellata*), already recorded by Merz and Dawah (2005), were collected by El-Hawagry et al. (2013, 2016) in AlBaha region. There is also an indirect indication of the presence of *B. zonata* and *C. capitata* in Jazan and Najran regions as per the report of ElAzzabi (2006). A full listing of fruit fly species recorded in Saudi Arabia is given in Table 3.

Fruit Flies of Kuwait, Qatar, and Bahrain

Amr (2021) listed 6 species of tephritids from Kuwait (originally as 7 species, one being a duplication). All of the species were listed under old invalid names. After verifying the valid names, there were 2 species from the Dacinae, and 4 species from the Tephritinae. There was no comment as to pest status, but two species are well-known pest species. No information is available about fauna of fruit flies from Qatar and Bahrain. A full listing of fruit fly species recorded in Kuwait is given in Table 3.

Biogeographic Distribution of the Arabian Fruit Fly Fauna

The majority of the fauna of fruit flies in Yemen are Afrotropical (Merz et al., 2006) and the same goes for the known fauna of Saudi Arabia (67% of the Aseer fruit fly fauna is Afrotropical, Merz and Dawah, 2005), because most of the sampling for fruit flies in Saudi Arabia was done in the southwest area of the country, close to the border with Yemen. In the UAE and Oman, there appears to be a greater presence of species from the Oriental and Palaearctic regions. For example, 11 out of the 20 (55%) of the species found in Oman are Oriental or Palaearctic species. The current total fruit fly fauna of the Arabian Peninsula is dwarfed by that of neighboring Iran as can be seen from table 3. Only 26 species are shared between Iran and countries in the Arabian Peninsula, which means that out of the total 166 species recorded from Iran, only about 16% are shared (Namin and Korneyev, 2018). This includes species such as the Oriental *D. persicus* and the Afrotropical *B. oleae*, but many of the species exclusively found in Iran belong in the Tephritinae and have Palaearctic distributions (e.g. *Tephritis* species) (Namin and Korneyev, 2018). They may also be found in cooler ecosystems in northern parts of the Arabian Penisula (Merz and Dawah, 2005). Probably many more species of fruit flies are awaiting discovery from unexplored or under-sampled parts of Arabia especially in northern, central and eastern areas of Saudi Arabia, and in the mountainous areas of Yemen and Oman.

Research on the Bio-ecology of Fruit Flies in Oman

Other than distribution and host plant records, there is little information about fruit flies in Oman. Ministry of Agriculture and Fisheries reports (MAF, 1991, 1992, 1993) and AlWahaibi et al. (2006) presented some information about parasitoids emerging from fruits collected in different parts of the country. There is also research examining the population dynamics of *Bactrocera zonata*, which is described by AlWahaibi et al. (2006) for the years 2003-2004. This research has been restarted in 2020 to include different fruit fly species and is still ongoing (second author, unpublished data). Unfortunately, similar kind of research output from other countries of the Arabian Peninsula was not available for study and analysis

Host Plant and Natural Enemy Associations

Two species of fruit flies (unspecified) and one parasitoid species (*Bracon*diae) emerged from *Ziziphus* fruits collected during July to September at Rumais Agricultural Research Station (MAF, 1991). In the same report, no fruit flies or parasitoids were reported from citrus. In a follow up report (MAF, 1992), the *bracon*id parasitoid species was identified as *Biosteres (Chilotrichia) persulcatus Silversti* (current valid name: *Fopius persulcatus* (Silvestri), Wharton and Yoder, 2023). Additionally, the *bracon*id wasp, *Psyttalia concolor* (Szepligeti), was recovered from fruit fly-infested *Ziziphus* fruits collected from Rumais (Barka) and AlMurair (Shinas) in 1991 (MAF, 1993). The report mentioned that the world-wide hosts of this parasitoid include: *Bactrocera oleae*, *Dacus* ciliatus, *Ceratitis capitata*, *Carpomyia incompleta*, and *Anastrepha suspensa*. A list of agricultural insects and mites from Oman contained an unconfirmed *Biosteres vandenboschi* (*Bracon*idae, current valid name: *Fopius vandenboschi* (Fullaway), Wharton and Yoder, 2023) which emerged from *Ziziphus* fruit infested by *Carpomyia incompleta* in Nizwa in 1977 (MAF, 1992).

According to AlWahaibi et al. (2006), most of the instances (81%) of emergence of parasitoids from fruit fly-infested fruits were linked with *Ziziphus* fruits. Additionally, 78% of *Ziziphus* fruit samples, producing *Carpomyia* flies, were associated with one or more species of a reddish-brown *bracon*id wasp belonging to the genus *Opius* (*Bracon*idae). Fruit samples from which *B. zonata* emerged were much less associated with parasitoids, with only 15% yielding any parasitic wasps. Some of these wasps belonged to the *Bracon*idae (genus *Opius*), while other wasps, which were black in color, belonged to the Figitidae (subfamily Eucoilinae, genus not identified). *Bracon*id and figitid wasps respectively made up 63% and 37% of the fruit samples yielding parasitoids. Figitid parasitoids were collected exclusively from Salalah in Dhofar. On the other hand, *Opius* wasps, associated with *B. zonata*, were collected from both northern Oman governorates and Dhofar. Host plants for parasitoids associated with *B. zonata* included *Ziziphus*, citrus, and guava. No parasitoids were associated with the other three fruit fly species (*D. ciliatus*, D.longistylus=*D. persicus*, and D. *nr. mulgens*) collected in this study. It appears from above that *Carpomyia* spp. appear to be under good levels of natural biological control, which was not the case for *B. zonata*. However, the actual levels of parasitism were not measured in this study.

AlAnsari (2009) reared *Bactrocera olea* from cultivated olive (*Olea europea*) fruits at one site in AlJabal AlAkhdhar. This fruit fly species was not recovered from wild olive fruits. This same author presented distribution and host plant data for five other fruit fly species (*B. zonata, Dacus ciliatus, D. longistylus* (a misidentification, probably *D. persicus*), *C. incompleta*, and C. *vesuviana*).

Fruit flies were surveyed in Dhofar (Salalah and Taqah) in 2015 (MAF, 2015) by using methyl eugenol (ME) traps and fruit samples from farms and market. Other than indication of the species of fruit flies (stated above in the section on fauna of fruit flies), there was also emergence of at least seven species of parasitoids (five *Bracon*idae, and two from undetermined families). One interesting observation was the emergence of *C. incompleta* from ivy gourd (a cucurbit), although this species is well known to be restricted to *Ziziphus* sp. It was also reported that *B. dorsalis* was dominant in ME traps catches, and that fruit fly numbers decreased during July and August due to the effects of the monsoon. Although the host plant of the previously mentioned parasitoids was not mentioned, *Ziziphus* was indicated as the host plant for five parasitoid species in a follow-up survey (MAF, 2018). All of these species belonged to the *Bracon*idae as per the shown images in the report. In a survey of cucurbits and other vegetables (egg plant, bellpepper/chilli, okra) in 25 villages across nine wilayats in AlBatinah South, AlBatinah North, and AlBuraimi, only *D. ciliatus* was recovered and it was collected only from cucurbit crops (MAF, 2020a). The determination of this species was based on both morphological and molecular analysis. No fruit flies emerged from egg plant, bellpepper/chilli, or okra. Moreover, in the same report, *B. zonata* and C. *vesuviana* in addition to the *bracon*ids *Fopius vandenboschi* and *Diachasmimorpha longicaudata* were recovered from *Ziziphus* fruits. From the above observations, it appears there is a strong association between *Ziziphus* and fruit fly parasitoids in Oman. It can by hypothesized that the collected parasitoids are mostly native parasitoids, highly co-evolved with

Ziziphus trees, especially the native Z. spina-christi (L.)Desf.

Population Dynamics of Bactrocera zonata

AlWahaibi et al. (2006) studied the population dynamics of *B. zonata* in three sites (Barka, AlMusanaa, and Sultan Qaboos University Agricultural Experiment Station SQU-AES) using methyl eugnol (ME) lures placed in MacPhail traps during the period from May 2003 to June 2004. In AlMusanaa and Barka, five male lure traps were hung in each farm at a height of 1.7-2 m on three types of fruit trees. The traps were checked biweekly and any trapped fruit flies were collected into a container for counting. Traps were refilled with a new ME plug every 2-3 months. One trap was also set at SQU-AES. Fruit flies were identified to species and counted. Data was tabulated per trap, and totals and means were calculated for each site and date combination. One distinct pattern observed in the Barka farm in 2003 and repeated in 2004 (Figure 5) is that the average number of male fruit flies per trap was relatively high in April and May 2003, hovering around 1000 flies per trap. This peak was followed by a sharp decline to reach a minimum of about 100 in late June 2003 and about 250 in late June 2004. The other observation, backed only by data from a single year, is the sharp increase in male fruit flies numbers during July and August above the 1000 mark, reaching a peak of about 5000 flies in late August 2003. This was followed by a nearly stable population hovering around the 1000 level until early December. This was then followed by a sharp decline in male numbers to levels below 500, remaining until around the end of February 2004. By the beginning of April 2004, male populations picked up again reaching levels above 1000 per trap and peaking in mid May 2004, with about 2500, before declining again until the end of June 2004.The patterns in the population dynamics in the Barka farm was mirrored in the data from AlMusanaa farm and SQU-AES. It is also interesting to note that the Barka farm recorded the highest male fruit fly numbers among the three sites at about 5000 per trap, while both the AlMusanaa and SQU-AES traps never exceeded 1400 per trap. This could be due to heavier pesticide use in both the Al-Musanaa and SQU-AES sites relative to the Barka site where little or no pesticide was used (confirmed by observations and communication with people in charge in the three sites) or due to difference in available fruit sources (number of trees) in the three sites.

Fruit Fly Management Research in Oman

Other than research articles reviewed in the section on fauna and bio-ecology of fruit flies in Oman, there has been little interest in conducting major investigations of fruit flies of economic importance and their management in Oman. Only within the last 10 years, there has been growing interest in conducting research dealing with control of fruit flies. The following is a summary of research work dealing with management of fruit flies since the 1980's.

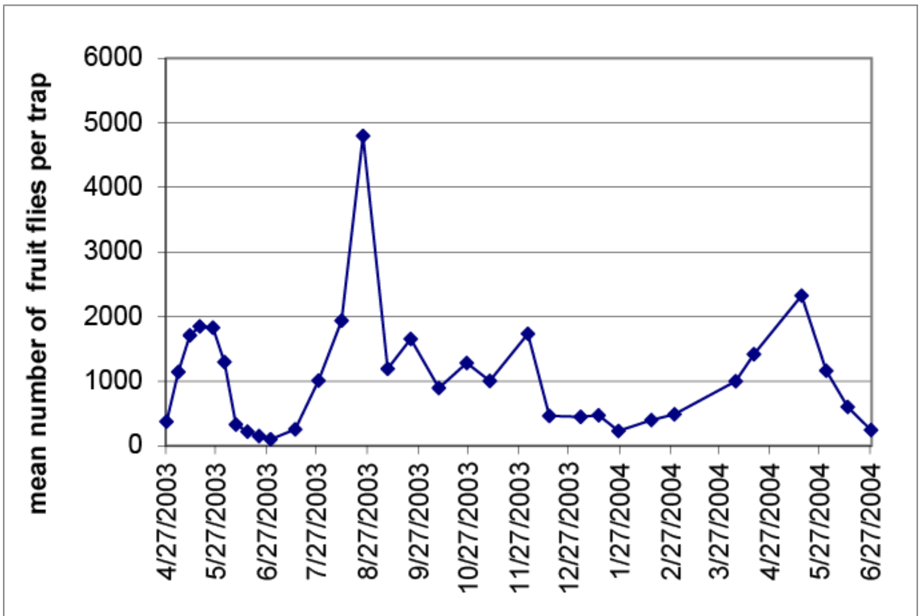


Figure 5. *Population dynamics of male B. zonata caught in methyl eugenol traps in Barka from April 2003 to June 2004. Source: AlWahaibi et al. (2006).*

Fruit Flies on Cucurbits and Fruit Trees: Identification and Management Recommendations

The misidentification of the fruit fly species attacking cucurbits in Oman (alluded to above in the above section on fauna of fruit flies) continued to around the year 1989. In a guide on management of Agriculture and Fisheries pests published by the Ministry of Agriculture (AlMujaini et al., 1989), melon fruit fly (*Dacus cucurbitae*) was stated as the pest damaging cucurbits. Recommended management included in the guide involved spraying of either dipterex (trichlorfon) or gardona (tetrachlorvinphos). Other recommendations included collection and burning of infested fruits and keeping the planted area fallow after harvest to kill any puparia in the soil by continuous exposure to the sun. In the same guide, *Dacus cucurbitae* was also considered as a pest of legume pods (e.g. cowpea).

Additionally, *Dacus dorsalis* was indicated as the fruit fly causing fruit damage in guava (probably a misidentification of *B. zonata*), while on citrus and mango only *Dacus* sp. was listed. On *Ziziphus* fruit (ber), the guide mentioned *Ziziphus* fruit fly (*Carpomyia incompleta*) as a severe pest that can cause the loss of the whole harvest. The recommended general management for fruit flies on fruit crops (based on the detailed description indicated for guava) was spraying with insecticides (organophosphates) every 10-15 days from the time of fruit formation until 10 days before harvest, not leaving mature fruits on trees without harvesting, and collection and burning of infested fruits. These pesticide spraying practices, started in the 1980's (or possibly since the 1970's) and continuing to at least 2010, could have had devastating effects on predators and parasitoids attacking eggs and larvae of fruit flies in fruits on trees and attacking larvae and puparia in the soil. In a booklet about cultivation of mango in the Sultanate of Oman (AlJabri, 2008), fruit fly was indicated to be a pest of mango, but the fruit fly species was stated as *Dacus* sp. Management advice included general sanitation and the destruction of fallen infested fruits by burning, in addition to the application of three organophosphate insecticides (dipterex, dimecron, dimethoate), with two of them being systemic.

Degree of Fruit Infestation

AlWahaibi et al. (2006) compared the number of adult fruit flies emerging per single fruit in five types of fruit: mango, guava, Indian almond, citrus, and cultivated *Ziziphus* (large-fruited). Mango (mean= 30) produced the highest number of adult fruit flies per single fruit, followed by guava (mean= 17), Indian almond (mean= 11), citrus (mean= 10), and *Ziziphus* (mean= 2). Mango had a significantly (p=0.0011) higher number of adult fruit flies per single fruit than Indian almond and *Ziziphus*. The large size of mango relative to the other four fruits could explain the relatively higher emergence from it. Citrus represented various cultivars from the smaller fruited lime to the large fruited sweet lime, oranges, and grapefruit. However, the difference in emergence from guava and Indian almond is smaller than expected given the much greater volume of flesh in the fruits of guava relative to Indian almond. Moreover, the low emergence from large *Ziziphus* fruits is in sharp contrast with its greater volume of fleshy material relative to Indian almond. Thus, it seems likely that factors other than fruit volume are important in determining the number of fruit flies developing in a single fruit. Some fruits could produce more attractive chemicals (Papadopoulos et al., 2006) to ovipositing female fruit flies than others. These chemicals could be in higher concentration in some fruits. This could lead to females laying more eggs in certain fruit species. Alternatively, some fruits could contain tissues that are more nutritious than tissues in other fruits or could hold distasteful and/or toxic compounds. This could result in differential development and survival of fruit fly larvae in different fruits, which could ultimately affect the number of emerging adults. Another possible explanation, at least in the case of *Ziziphus*, is the higher level of parasitism (see above) which could reduce the numbers of emerged adults. The large populations of *B. zonata* on Indian almond in Mauritius and other Indian ocean islands as reported by White et al. (2000) is indicative that some host fruits could be more highly preferred than others and that fruit volume is not the only determining factor.

Insecticide Trials

Insecticide trials to control fruit flies were conducted by the Ministry of Agriculture and Fisheries at Rumais Agricultural Research Center in 1980 and 1981 (MAF,]1983a, 1983b). The first experiment was carried out to determine the effect of spraying of a number of insecticides on degree of damage by *Dacus ciliatus* on watermelon (stated as *Dacus cucurbitae*, but the included image showed *Dacus ciliatus*). The 1980 experiment tested three insecticides with and without bait (presumably protein bait), but unfortunately it did not have a control, so it is difficult to reliably judge the actual effect due to the applied insecticides. However, the 1981 experiment had four other insecticides (pirimiphos-methyl, formothion, thiometon, fenvalerate) and a control for comparison, so conclusions can be made. All of the four applied insecticides produced significant decrease in the infestation of fruits relative to the control (2.75-9.71 % infested fruits in treatments vs. 24.5% in the control).

An experiment was conducted in AsSuwaiq in 2020 by the Ministry of Agriculture, Fisheries, and Water Resources (MAFWR, 2020b) to compare the efficacy of seven insecticides for the control of fruit fly (species not indicated) on pumpkin. Three of the chemicals tested were botanical insecticides (Varad, Act Altra, Kingbo) while four were synthetic insecticides (Movento, Sumi alpha 5 EC, Oberon, Prime Sivanto). No damage by the fruit fly and no fruit fly stages were observed in all treatments and control. The obtained results were not conclusive as no significance difference was detected between the insecticide treatments and the control in terms of level of damage and the yield of marketable fruit. Moreover, catches of fruit flies in pheromone traps were counted before application of the treatments and 3, 7, and 10 days afterwards. No significant difference were detected between catches before and after the application of the treatments. As no details were given about the lure used to attract the fruit flies, it is presumed that the commonly available methyl eugenol lure was used. This lure does not normally attract fruit fly species attacking cucurbits, and in Oman it attracts only *B. dorsalis* and *B. zonata* which target fruits of trees. According to the authors, the experiment will be repeated in the future using more susceptible cucurbit crops such as zucchini, melon, and watermelon.

Lures for Monitoring and Management

In a study by AlBusaidi (2013), the efficacy of different lure materials for the monitoring and potential management of *B. zonata* was tested. These lures were installed in MacPhail traps hung on trees in a farm in AlMusanah from May to October 2012. In one set of experiments, traps separately containing one of four different formulations of methyl eugenol (ME) either had dichlorvos insecticide strip or no strip was added. The control traps were with and without dichlorvos. Results showed that ME traps containing dichlorvos had lower male catches than traps without dichlorvos. This could be due to some repellent effect of dichlorvos toward *B. zonata* males. In another set of experiments, traps with five different formulations of ME, torula yeast (3 concentrations), protein hydrolysate, or GF-120 (attractant+spinosad, Dow AgroSciences) were set up in the same farm to compare their attraction power. Although the ME formulations caught a much greater number of male *B. zonata*, tourla yeast caught relatively more female *B. zonata* than protein hydrolysate, GF-120, and the five ME formulations.

AlSaadi (2022) conducted experiments in a mango farm in Qurayyat (Muscat Governorate) from April to October 2021. The female lure experiments involved testing of traps containing different urea concentrations without ground water melon seeds (ground WM seeds), traps with different urea concentrations plus ground WM seeds (to increase rate of ammonia production), traps with other ammonia-producing lures, and traps with protein based lures. In male lure experiments, methyl eugenol (ME) products from different manufacturers were tested for efficacy. In addition, trap design, lure status (dry or immersed in water) and ME longevity were tested. Results showed that as urea concentration increased, the fruit flies catch also increased. The addition of ground WM seeds (at 0.2g per 700 ml water) to different urea concentrations significantly increased fruit fly catches relative to treatments containing urea only. The number of fruit flies caught in urea with ground WM seeds was similar or higher than in the baker's yeast and marmite yeast treatments but was lower than in the torula yeast treatment (which had the highest catches) It was also noticed that urea treatments (different concentrations with and without ground WM seeds) were attracting a high percentage of fruit flies in the total fly catch, while other tested lures (especially yeast-based lures) were either attracting equal percentages of fruit flies and other flies, or attracting a low percentage of fruit flies. There were significant differences among ME lures from different manufacturers, with Chemtica ME being the best in terms of having the highest catch of fruit flies when water was added to traps. Additionally, SunPet jar traps (750 mL clear plastic jar with four holes) had higher fruit fly catches when lures were applied in water inside traps, but MacPhail trap had higher catches when lures were applied without water. The effect of ME lure starts to weaken after the passage of four weeks. This study showed that the addition of water to ME traps generally increases the catches of male fruit flies but this could be modulated by trap design. Additionally, it indicated that urea (especially when mixed with ground WM seeds) could be an effective, inexpensive and environmentally friendly (due to lower catches of non-target flies) substitute to synthetic insecticides, especially if sufficient number of traps per tree are placed over a large agricultural area.

Physical Barriers

AlAnsari (2009) conducted an experiment to test the effect of bagging of mango fruits on infestation by fruit flies (mostly due to *B. zonata*) and marketability. He used five mango cultivars (Abosenara, Zafaran, Rasfory, Totapuri, and Omani), and three fruit bagging treatments (green mesh/net, agryl fabric, newspaper) in addition to a no bagging control. There were no significant difference in terms of the percentage of the sum of marketable (zero oviposition marks) and consumable fruits (less than 5 oviposition marks) among cultivars. However, the percentage of the sum of marketable and consumable fruits was significantly different among the different bagging treatments. All bagging treatments produced significantly higher percentage of marketable and consumable fruits than the control (0-44%), and the agryl (94-100%) and newspaper (95-100%) bagging treatments produced a higher percentage of such fruits than the green net bags (66-95%), although this difference was not consistently significant for all cultivars. In the same study, the different bagging treatments were also compared in terms of cost (least for newspaper followed by agryl), labor time for installation (least for green net), fruit color visibility (in green net only), sunscald (in green net only), and spoilage due to rain (occurred in newspaper only).

AlRahbi (2019) conducted a study on the efficacy of agryl row cover for the reduction of zucchini infestation due to the Ethiopian fruit fly, *D. ciliatus*. The experiment was conducted at SQU-AES. Three row cover treatments plus control were tested. These consisted of a full cover treatment (sides and top were covered), two enclosure treatments (only sides were covered, with and without sticky traps), and a control with plants fully exposed. Sticky traps were used to determine flight height pattern of *D. ciliatus* and to test their potential for the reduction of infestation. Above treatments (including control) were applied to lines of 4-5 zucchini plants replicated 3 times. Full cover and enclosure treatments produced consistently and significantly lower infestation levels and higher yields (commercial size fruits) than the control. Although infestation levels were significantly lower in the full cover treatment, the yield (weight-wise) of zucchini fruit was highest in the enclosure treatments. This could be due to larger and healthier fruits in the enclosure treatments, possibly produced from a combination of greater access to efficient pollinators such as bees, lower humidity (less fungal and bacterial disease), and more light. The zucchini variety used in the experiment (*Cucurbita pepo* var. Anita) proved to be highly parthenocarpic as large numbers of fruits were produced under the full cover treatment. Most *D. ciliatus* adults were caught at a height of 25-35 cm, which matches the low height of their cucurbit hosts. The top yield of about 159.8 g per zucchini plant recorded in this experiment (in enclosures without sticky traps) could be improved further by protecting plants from viral infection through placement under full agryl cover until the time of appearance of female flowers followed by removal of top cover and keeping only the sides covered. The effectiveness and economic feasibility of this management method needs to be studied with respect to cost and profitability, application methods (around single rows or whole field), and extension of use to different cucurbit crops.

Quarantined Fruit Flies

In the list of quarantined pests published by the Ministry of Agriculture and Fisheries (MAF) around 1997 (publication date not indicated, MAF undated-a), these fruit flies were mentioned: *Anastrepha ludens, Carpomyia vesuviana*, *Certatitis capitata*, *Ceratitis rosa, Dacus* sp., and *Rhagoletis cerasi.* The quarantined pests in the larger list published by MAF between 2007 and 2010 (publication date not indicated, MAF undated-b) included: five *Anastrapha* spp. (*fraterculus, ludens, obliqua, serpentine, suspensa*) , six *Bactrocera* spp. (*atrisetosa, cucurbitae*, *melanotus, minax, tryoni*, *tsuneonis), Ceratitis rosa,* and *Rhagoletis pomonella*. In the same publication, three *Bactrocera* spp. (*dorsalis, zonata*, *olea*), *Dacus ciliatus* (listed as *Bactrocera ciliatus*), *Dacus vertebratus, Carpomyia incompleta*,, *Carpomyia vesuviana*, and *Ceratitis capitata* were listed as non-quarantined pests restricted by law. It appears strange that *C. capitata* (Mediterranean fly) was not a quarantine pest although it was still not recorded from Oman at that time. The same is true for *B. olea* and *D. vertebratus*.

Fruit Fly Management Research in other countries of the Arabian Peninsula

Only two studies from Saudi Arabia, and one study from Yemen were available. The following is a summary of these studies. AlDawood (2013) examined the infestation of small (young) and large (old) fruits of two varieties of zucchini (*Cucurbita pepo*) by *D. ciliatus* in two sites in the Riyadh area (Saudi Arabia) from late May to middle of June 2003. He also looked at changes in the number of harvested fruit and infested fruit over a period of about six weeks. Moreover, he performed an analysis to determine possible correlation between weather factors and infestation during the study period. He found infestation to be consistently and significantly higher in younger smaller fruit than in larger older fruits in one of the sites. Although there was no significant difference in infestation between the hybrid and regular varieties of zucchini, there was a significant difference in infestation between the two sampled sites. Infestation increased during the month of May, peaking at the end of May, then a decline was observed during the first two weeks of June. No consistent and strong correlation was detected between infestation and temperature, humidity, or wind speed.

Ghanim et al. (2014) tested five concentration (1, 2, 3, 4, 5%) of each of six different ammonia compounds (tri-ammonium phosphate, ammonium carbonate, ammonium acetate, ammonium chloride, ammonium thiocyanate, ammonium dihydrogen phosphate) in terms of their attractiveness to *C. incompleta* on *Ziziphus spina-christi* (sidr) in the AlQaseem area of Saudi Arabia during 28 days from early March to early April 2013. He found that tri-ammonium phosphate was generally the most attractive compound to *C. incompleta* followed by ammonium carbonate. Ammonium dihydrogen phosphate did not attract any *C. incompleta*. There was evident increase in trap catches with increase in concentration for tri-ammonium phosphate (regression between the two factors showed a strong positive relationship), while for other compounds such as ammonium carbonate, there appeared to be a decrease in trap catches with increase in concentration. Moreover, significantly more females were captured in the case of tri-ammonium phosphate for all concentrations, while only the lowest concentrations of ammonium carbonate and ammonium acetate caught more females. There was no significant difference between numbers of females and males for the other compounds. There was also a general decline in trap catches for all tested compounds during the period of the study (more evident toward late March and early April), possibly due to general decline in the population of *C. incompleta* or due to degradation of the compounds (possibly caused by microorganisms in the tested solution) with the passage of time. However, there was some fluctuation in catches for certain concentrations of some of the compounds, which could have been due to fluctuation in the population of the fruit fly. The authors recommended the use of tri-ammonium phosphate (at 4 or 5%) as an effective lure for *C. incompleta* in pest management programs.

In southern Yemen (Peoples' Democratic Republic of Yemen) in 1975-1976, Ba-Angood reported using insecticides (one of them baited with protein hydrolysate) to control *Dacus frontalis* on watermelon and sweet melon. It is interesting to note that *D. frontalis* was the major pest reported on here, and not *D. ciliatus*, the usually more common fruit fly species damaging cucurbits in the Arabian Peninsula.

Conclusion

It is hoped that this review has managed to summarize and synthesize the current state of knowledge about tephritid fruit flies, a diverse group of insects, which has evident economic and ecological importance. Due to the very extensive literature on fruit flies, the undertaken review tried to cover the most important topics in general terms allowing the reader to search for more details about particular aspects using the many mentioned cited works throughout. Indeed, each of the covered topics deserves a dedicated review in the future. More importantly, this review provides the first attempt to compile information about fruit flies in the Arabian Peninsula with emphasis on the Sultanate of Oman in terms of the fauna, bio-ecology (host plants and parasitoids), and pest management. Most of the research works into bioecology and pest management comes from Oman, with only three articles from neighboring countries in the Arabian Peninsula. However, this big gap could be an artifact of the greater availability of Oman's literature to the authors. It is possible that many unpublished works or hard copies of research reports from other countries in the Arabian Peninsula are not accessible because they are not available online. We hope that this review provides a basis for more research on fruit flies in the region from both an economic and environmental perspective. In Oman, the non-frugivorous fruit fly species are under-represented in the fauna, and different natural ecosystems are awaiting to be explored to discover more species, some of which could be new to science. Research to better understand the local ecology of fruit flies, especially the pest species, is lagging behind. The same goes for pest management research as can be seen from the dearth of publications from Oman and the Arabian Peninsula compared to the huge research output from other areas in the Middle East, North Africa, the

Indian subcontinent, and the world at large. It is recommended that researchers in the region should focus research in the future on the less touched aspects alluded to in the general review such as biological control using natural enemies, sterile insect methods including the promising use of chemosterilants, and area-wide integrated pest management.

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