

Key fruit flies species (Diptera, Tephritidae) reported in Africa and presenting a biosecurity concern in Morocco: An Overview

Jamal BEN YAZID

Laboratory of Biochemistry and Biotechnologies, Mohamed first University, Faculty of Sciences, Oujda, Morocco

Zouheir CHAFIK

Laboratory of Plants and Microorganisms Biology, Mohamed first University, Faculty of Sciences, Oujda, Morocco

Imane BIBI

Laboratory of Biochemistry and Biotechnologies Mohamed first University, Faculty of Sciences, Oujda, Morocco

Anwar BOUSAMID

Laboratory of Plants and Microorganisms Biology, Mohamed first University, Faculty of Sciences, Oujda, Morocco

Ez-zahra KHARMACH

Laboratory of Biochemistry and Biotechnologies Mohamed first University, Faculty of Sciences, Oujda, Morocco

Fruit crop species are from the most widely cultivated crops in Morocco. However, the sustainability of this lucrative business is threatened by infestations of invasive fruit flies (Diptera: Tephritidae) that may inflict heavy economic losses to the country if their invasion occurs. At this time, Medfly is the main fruit fly which causes a high loss and is a phytosanitary concern to fruit species. The distribution and abundance of the major frugivorous tephritids are influenced by host presence, climatic factors, and their potential of invasion. Two types of economic impact of fruit flies are distinguished, direct losses in the yield and indirect losses due to the loss of markets caused by quarantine restrictions imposed by importing countries to prevent the entry of exotic flies in their territory. The most important invasive tephritid fruit flies present in Africa and that may constitute a risk of invasion into Morocco are *Bactrocera dorsalis*, *Bactrocera zonata* and *Bactrocera cucurbitae*. Also, the indigenous species within genera *Ceratitis* ((*Ceratitis quinaria*, *C. anonae*, *C. catoirii*, *C. cosyra*, *C. silvestrii*, *C. ditissima*, *C. fasciventris*, *C. rosa*, *C. quilicii*) and *Dacus* (*Dacus latifrons*, *D. vertebratus*, *D. bivittatus*, *D. punctatifrons*, *Dacus ciliates*) may present a risk of introduction to Morocco. These fruit fly species are characterized by having a wide range of host plants and a wide distribution throughout Africa. The risk of spread is enhanced by the lack of control and the weakness of the identification process of the present and newly introduced species. This review presents the status and the distribution of major fruit fly species present in Africa, gives an overview of their host plants, new invasions and means of detection and phytosanitary measures to implement in Morocco to avoid any invasion originated from other African countries.

Keywords: Africa, Fruit fly, Distribution, host plant, Invasion, biosecurity, and Morocco.

INTRODUCTION

Due to its economic importance, the invasiveness of tephritidae throughout the world is attracting great attention in the fields of plant protection, plant quarantine, biosecurity and invasive biology. Predicting which of the hundreds of fruit flies has a higher probability of risk of introduction into a given region is a major challenge but it can be facilitated by collecting information on the

geographical distribution of these flies and monitoring the territories of their presence.

The fruit flies (Diptera, Tephritidae) are pests of economic importance for many countries and species of wild and cultivated fruit plants worldwide (White and Elson-Harris 1992). Different stages of larvae of most fruit flies species are phytophagous and attack tissues of a wide spectrum of host plants, especially fruits and flowers, and cause a significant loss of crop yields. In many countries, the economic importance of many fruit flies species is high and constitutes a key concern of biosecurity and phytosanitary surveillance (mainly in the genera *Ceratitis*, *Anastrepha*, *Bactrocera*, and *Rhagoletis*).

From the list of species of fruit flies, the most economically important species are *Bactrocera oleae* (Rossi, 1790), *Bactrocera dorsalis* (Hendel, 1912), *Bactrocera depressa* (Shiraki, 1933), *Bactrocera cucurbitae* (Coquillett, 1899), *Ceratitis capitata* (Wiedemann, 1824), and *Ceratitis rosa* Karsch, 1887) that have been successful quarantine pest of prime priority in risk analysis over the past years worldwide (White et al., 2000 and Papadopoulos et al., 2013).

Fruit flies have a strong adaptation to several biotopes, climatic conditions, and different ranges of host fruits (Aluja et al., 2003). Those elements make control strategies more difficult and require the development of modern tools to pest risk analysis and establish new patterns of assessment. Because its high risk of invasion, many advances in biological control strategies, Sterile Insect Techniques, quarantine treatments, and next-generation tools have been described (Montoya et al., 2000; Aluja et al., 2013; Ali et al., 2016, 2017; Bachmann et al., 2015; Castánón-Rodríguez et al., 2014; Cancino et al., 2014; Landeta-Escamilla et al., 2016). The phytosanitary and biosecurity challenges of fruit fly management, in the future, will require continued emphasis on the principles of Integrated Pest Management (IPM) and a broadening of the focus beyond pest control.

Among insect pests, tephritidae have greater economic importance and impact than other insects in the international trade of horticultural products (Hendrichs, 1996). Countries with the presence of the major pests spend millions of dollars each year on control and face trade sanctions to impose treatments on their exporters and stakeholders of plant products before export.

Although these treatments are effective, the frequencies and the volumes of fruit products exported to countries with "free" or "low" pest status raise biosecurity and phytosanitary concerns (Dhami et al., 2016). To maintain fruit fly "free" status, New Zealand as an example, with one from most rigorous biosecurity systems, spends approximately NZ \$1.4 million per year on only post-border quarantine inspection (Dhami et al., 2016). However, the status of fruit fly "free" country provides to Chile, for example, an increase in exports of up to 50% of total fruit production (Retamales and Sepúlveda, 2011).

In addition to direct losses in yields, indirect losses associated with quarantine restrictions on fruit fly-infested crops have been enormous and limit exportations to large lucrative export markets in Europe, the Middle East countries, Japan, and the USA, where the insects are included in quarantine listed pests. To develop Species distribution models, as a tool of predictions, it is suitable to collect information about bio-ecology and spread of invasive species (Thuiller et al. 2005; Elith et al. 2006; Merow et al. 2013) and to assess the occurrence of novel invasions such as that observed within the region with the same bio-ecological conditions. The majority of fruit fly species (Diptera: Tephritidae) are invasive pests of horticultural crops throughout the world because of their ability to adapt to the climates of various regions, their high polyphagia and their rapid reproduction (Sarwar, 2015).

FRUIT FLIES AND MOROCCAN BIOSECURITY

In Morocco, *Ceratitis capitata* is a major and the only true fruit fly of economic importance, due to the loss in yield that it causes to a large spectrum of fruit species and is of phytosanitary concern.

To avoid the introduction, spread and establishment of other species of fruit flies, Moroccan phytosanitary authorities are called to conduct, on a regular basis, pest risk analysis and survey on the main fruit flies species representing a high risk of invasion to Morocco (Eaini and Mazih, 2018).

Because of the repetitive interceptions of medfly in Citrus shipments coming from Morocco in Russia, the phytosanitary authorities notified Morocco and imposed quarantine restrictions on Citrus exportations to Russia. Also, APHIS (US Animal and Plant Health Inspection Service) prohibited the importation of citrus from Morocco, because of the interception of live larvae of *Ceratitis capitata* in Citrus cargo exported from Morocco. This ban has been lifted after imposing on Moroccan exporter adds phytosanitary measures generating new costs and more restrictions. In this context, Moroccan authorities should be proactive to avoid the introduction of new invasive fruit flies which may threaten the access of Moroccan products to lucrative markets or imposed more restrictions on its exportation of horticultural crops (APHIS, 2016).

FRUIT FLIES IN AFRICA AND THEIR DISTRIBUTION

White and Elson-Harris (1992) described 915 fruit fly species in Africa comprising 148 genera, out of which 299 species developed in either wild or cultivated fruit. Historically, the fruit flies species with economic importance in Africa are comported within three main genera: *Bactrocera* Macquart, *Ceratitis* MacLeay, and *Dacus* Fabricius (White and Elson-Harris 1992). Several studies showed that with the increase of international trade of plants and plant products into Africa, in 2003, a new species, *Bactrocera dorsalis* (Hendel) has been introduced to Africa from the Indian subcontinent (Lux et al. 2003; Mwatawala et al. 2004; Drew et al. 2005) and was detected in more than 30 countries of different regions of Africa (Ekesi et al. 2006; De Meyer et al. 2007; Correia et al. 2008; Rwomushana et al. 2008; Goergen et al. 2011; Vayssières et al. 2014; Hussain et al. 2015; Isabirye et al. 2015). Furthermore, other Asian *Bactrocera* species such as *Bactrocera zonata* Saunders, *Bactrocera latifrons* (Hendel) and *Bactrocera cucurbitate* (Coquillett), have also been reported in many areas of Africa, and islands of the Indian Ocean, causing economic and crop damage with significance effect in African plant protection systems (De Meyer et al. 2007; Shehata et al. 2008; Elnagar et al. 2010; Mwatawala et al. 2010). The genus *Bactrocera* is one of the largest groups of fruit flies comprising more than 500 species, many of which are fruit pests of economic importance (Drew & Romig, 2013).

The lack of a strong plant protection system and the absence quarantine restrictions Trans borders between many African countries allows an intensive trade and free movement of fruits. This movement makes Africa highly vulnerable to the introduction of alien fruit fly species that attack several fruit host plants. Both invasive and indigenous fruit fly species have been introduced spread and established in different seasons, cultivated and wild host plants and bioclimatic areas as reported by De Meyer et al. (2007); Lux et al. (2003) and De Villiers et al. (2013).

***Bactrocera dorsalis*, the oriental fruit fly**

The name given to this pest is *Bactrocera invadens* Drew, Tsuruta & White. It is also known as the 'African Invader Fly'. This fruit fly was introduced to East Africa from Sri Lanka and further invaded entire Sub-Saharan Africa. New studies confirmed that *B. invadens* was found to have similar biological characteristics as the complex of species constituting the group *B. dorsalis* (Drew 1994). Also, Because of this similarity, *Bactrocera invadens* was synonymized with *B. dorsalis* in 2015 (Schutze et al. 2015).

Geographical distribution

The first report was in Kenya in 2003 (Lux et al. 2003), followed by a rapid spread causing now a presence in more than 30 countries beyond its native range. Its geographical distribution (Fig.1. (A)) In Africa covers Angola, Benin, Comoros Archipelago, Botswana, Burundi, Cameroon, Central

African Republic, Cape Verde, Chad, Côte d'Ivoire, Mayotte, Burkina Faso, Democratic Republic of Congo, Ethiopia, Eritrea, Equatorial Guinea, Gabon, Gambia, Republic of the Congo, Guinea, Guinea Bissau, Kenya, Liberia, Ghana, Mali, Mauritania, Mozambique, Senegal, Sierra Leone, South Africa, Namibia, Niger, Nigeria, Sudan, Swaziland, Tanzania, Togo, Uganda, Zimbabwe and Zambia (Drew et al. 2005; Vayssières et al. 2005; Mwatawala et al. 2006a; Correia et al. 2008; Rwomushana et al. 2008; Goergen et al. 2011; Manrakhan et al. 2011; Virgilio et al. 2011; De Meyer et al. 2008, 2012; Ibrahim Ali et al. 2013; Aidoo et al. 2014; Massebo and Tefera 2015; Hussain et al. 2015; Isabirye et al. 2015). It was discovered in Sri Lanka soon after it was reported from Africa (Drew et al. 2005).

Impact

It is a pest of economic importance, for example, the importation of fruit species that are hosts of *B. dorsalis*, from countries with the presence of this pest such as Kenya, Tanzania, and Uganda is currently banned in Seychelles, Mauritius, and Republic of South Africa and restricted by a regulation resulting on the USA banning the importation of several cultivated fruit species from African countries where *B. dorsalis* has been reported (USDA-APHIS 2008; Ekesi et al. 2016). Furthermore, its establishment would have a serious impact on the environment, following the adoption of chemical and/or biological control programs to control this invasive fly. Besides its Invasive character in some countries, *B. dorsalis* has been confirmed to be highly competitive with native fruit flies where it has established, quickly becoming the dominant fruit fly pest (Duyck et al., 2004; Vargas et al., 2007; Vayssières et al., 2015).

From all species of fruit flies present in Africa, exotic and native, *B. dorsalis* ranks the first on the African continent and causes remarkable economic damage to fruit production. It causes economic and crop losses that exceed 80 % in economic crop production or up to 100% of unprotected fruit. Because of the effort that must be done to eradicate and to control it, when introduced to a country, *B. dorsalis* had an economic impact and generates high costs.

In California, USA authorities estimated that the cost of not eradicating *B. dorsalis* would range between US\$ 44 and 176 million in damage caused to crops, increasing pesticide spray, and export quarantine restriction. In Hawaii, annual losses in major fruit crops caused by *B. dorsalis* may exceed US\$ 3 million (Culliney, 2002). The cost of eradication was US\$1 million in Mauritius Island (Seewooruthun et al., 2000), more than 200 million Euro in the Ryukyu Islands in Japan (Kiritani, 1998), AUS\$ 33 million in northern Queensland and in Australia, the annual cost to control the pest, if it had been left established, was estimated to be AUS\$ 7-8 million (Cantrell et al., 2002)

Detection and Inspection

Locally grown fruits should be monitored for *B. dorsalis* presence by a trapping network based on food or food extract attractant providing data on the presence or absence of this species flies captures. To avoid *B. dorsalis* introduction, spread and establishment it is recommended to implement a Prevention, Control and Early Warning Systems.

Phytosanitary measures

The source of risk of the introduction is the import of fruit containing larvae, either as part of cargo, or smuggled in passenger baggage or postal mails. In imported host fruits, samples should be taken to be inspected for presence of eggs or larvae of *Bactrocera dorsalis*. Fruits are checked for punctures marks in rind and suspected ones are cut open to be examined for egg or larvae presence. The identification of larvae required a deep knowledge or molecular tests. In many cases it is recommended to keep larvae in pupation media for emergence and to be identified easily. Passenger baggage should be inspected regularly to avoid the introduction of infested fruits smuggled by travelers from countries where *B. dorsalis* occurs.

Bactrocera zonata, the Peach fruit fly

Geographical distribution

Originated from the south and Southeast Asia, *Bactrocera zonata* invaded Africa and occurred in Egypt and Libya. Current reports signaled its presence in several regions of Sudan and suggest a spread toward southern regions of Africa (fig.1.B). Some authors concluded that there a potential risk of invasion for Eastern Africa and the sub-Saharan area. (De Meyer et al. 2007; Shehata et al. 2008; Elnagar et al. 2010; El-Samea and Fetoh 2006). Also, *Bactrocera zonata* is known to become established in Mauritius and La Réunion (Quilici et al. 2005).

Impact

It causes severe damage to some preferable fruit crops including peach, guava, and mango. Many other species of fruits are also host plants. In certain climatic conditions, its impact may be more notorious than other species of fruit flies as *B.dorsalis* (Kapoor, 1993).

Losses caused by *B. zonata* may achieve 25 to 100% in peach [*Prunus persica*], apricot [*Prunus armeniaca*], guava [*Psidium guajava*] and figs [*Ficus carica*] (Siddiqui et al., 2000). In Egypt, the rate of infestation caused by *B. zonata* in certain fruits including apricot and citrus were higher than those caused by *Ceratitis capitata*. This percentage may reach 20% of total fruits (Saafan et al., 2005). Economic losses may come from the cost of eradication measures and commercial restrictions due to quarantine barriers imposed by countries with status “free” from *B.zonata* and from direct yield losses caused by fruit damage (Vargas, 2015). Mauritius, la Réunion and Egypt had to abandon effort implemented to eradicate this fly species because they conclude that it is hard to achieve this goal. (El-Samea and Fetoh, 2006)

Detection and Inspection

Locally grown fruits should be monitored for *B. zonata* presence by a trapping network based on food or food extract attractant providing data on the presence or absence of this species flies captures. To avoid *B. zonata* introduction, spread and establishment it is recommended to implement a Prevention, Control, and Early Warning Systems. Methyl eugenol has been proven to be very effective to attract *B. zonata* males, so it is widely used to monitor this pest population. It may help to detect *B. zonata* presence in surveillance programs. It showed high effectiveness at very low concentrations and with high distances (up to 1 km) (Qureshi et al., 1992). Agarwal et al. (1995) reported that a mixture of a protein hydrolysate, insecticide, and methyl eugenol may obtain more effectiveness in *B. zonata* trapping.

When fruits are suspected, they should be cut open for check of larvae presence, collected larvae should be reared in containers with sand for pupation and emergence before being identified easily (Vargas, 2015).

Phytosanitary measures

Countries, where this fruit fly occurs, should develop postharvest quarantine measures that ensure fruits or vegetables are free from different live stages of *B. zonata*. Regular inspections in fields should be conducted by qualified personnel to provide required data on the infestation status of any shipments. Countries with status “free” from *B. zonata* but where could become established should require phytosanitary restrictions before importing host material from countries where *B. zonata* occurs and proceed to regular inspections of cargo, passenger baggage, and postal mails. Fruits should be checked for insect punctures and suspect ones should be cut open and checked for larvae presence. Phytosanitary measures should also be reinforced, if a need is, reduce risk on introduction, spread and establishment otherwise, Phytosanitary treatments may be required to export fruit hosts of this insect from countries where it is endemic or occurred.

Bactrocera latifrons, the solanum fruit fly

Geographical distribution

This species is native to Asia (Carroll et al. 2002; Shimizu et al. 2006). It was detected and reported for the first time in Tanzania in 2006 (Mwatawala et al. 2007). The exact time and point of entry of the pest into Tanzania are unknown. The second detection of this pest was reported in 2007 in Kenya close to the border area with Tanzania. This species does not occur in other areas in Africa (De Meyer et al. 2007, 2008).). It is of quarantine importance and has the potential to establish in other regions in Africa and coexist with native and invasive other fruit flies species (Fig.1. D)

Detection and Inspection

Fruit inspection recommended is similar to *B. dorsalis*. The field inspection is limited to the fruit inspection for marks or punctures or any necrosis that will cut open and checked for larvae because this species is not attracted by methyl eugenol or other cue lures. In Okinawa a sesquiterpene hydrocarbon, β -caryophyllene a new lure chemical is being developed (Nishida, 2014).

Phytosanitary measures

Countries free from this fly species, such as the mainland USA, forbid the import of susceptible fruit without strict post-harvest treatment including cold treatment in transit, heat treatment, fumigation, or irradiation (Armstrong and Couey, 1989). However, recent studies showed that *B. latifrons* is more heat tolerant than other fruit flies. Countries tend to restrict or avoid the importation of host fruits from countries, where *B. latifrons* occurs to mitigate the risk of introduction (Jang et al., 1999).

Zeugodacus cucurbita, the melon fruit fly

Geographical distribution

Zeugodacus cucurbitae or *Bactrocera cucurbitae* is an Asian species infesting mainly species of Cucurbitaceae. It was introduced and established in Africa earlier than the 1930 year as confirmed by the first specimens in collections from the African mainland (White, 2006; White et al, 2001). Its presence was restricted to eastern Africa and sub-saharan for several decades and has recently been reported from western Africa and Seychelles (White, 2006). *Bactrocera cucurbitae* has been recorded in several African countries from Benin, Burkina Faso, Burundi, Cameroon, Côte d'Ivoire, Democratic Republic of Congo, Ethiopia, Gambia, Ghana, Kenya, Malawi, Mali, Mozambique Niger, Nigeria, Sierra Leone, Senegal, Sudan, Tanzania, Togo, and Uganda (White and Elson-Harris 1992; Vayssières and Carel 1999; De Meyer et al. 2007, 2015). It is an important frugivorous pest of cucurbitacea species and causes losses that are variable among cultivated hosts (Mwatawala et al. 2009 and Jacquard et al., 2013) (Fig.1. E). The preferred species hosts are watermelon, pumpkin, and cucumber, grown in low land areas where the pest is abundant (Mwatawala et al. 2006b).

Detection and Inspection

As for several fruit flies, the inspection for the presence of *Zeugodacus cucurbitae* should be conducted by taking fruits, locally grown or samples of fruit imports, and check for puncture marks or similar blemishes. Fruits with symptoms should be cut open and checked for egg or larvae. To distinguish larvae from the other species of fruit flies it's recommended, so if time allows, transferring mature larvae to sawdust (or any pupariation media) to allow pupariation and emergence and obtain adult flies easy to be identified (sookar et al., 2012 and White and Elson-Harris 1992).

Impact

Studies reported that *Bactrocera cucurbitae* (Coquillett) or melon fly can, if uncontrolled, may cause up to 100% loss of yield. Females of *B. cucurbitae*, by its ovipositor cause punctures in the skin of fruits and lays their eggs in the rind (Srivastava and Butani 2009). The larvae damage the pulp of the fruit by feeding and burrowing out to pupate in the soil (Stonehouse et al. 2007).

Phytosanitary measures

The major risk of introduction is from the import of fruit containing larvae. This introduction may occur in commercial cargo or through the smuggling of fruit in airline passenger baggage or postal mails. The regular inspection of consignments may then be adopted as a tool to reduce the risk of introduction from the area where this pest occurs. For example, in New Zealand, Baker and Cowley (1991) reported that 7-33 interceptions of fruit flies have been recorded in commercial cargo and 10-28 smuggled in passenger baggage per year.

***Dacus bivittatus* fruit fly, pumpkin**

In studies conducted in Côte d'Ivoire *Dacus bivittatus*, represented approximately 0.42 % of fruit flies reared from mango (Hala et al. 2006 and N'depo et al. 2013).

Also, this fruit fly was reported in many African countries such as Angola, Benin, Cameroon, Congo, Côte d'Ivoire, Democratic Republic of Congo, Ethiopia, Gabon, Ghana, Malawi, Mozambique, Guinea, Kenya, Madagascar, Nigeria, Senegal, Sierra Leone, South Africa, Tanzania, Togo, Uganda, Zambia, and Zimbabwe (White and Elson-Harris 1992) (Fig.1. H).

Dacus ciliatus

Geographical distribution

In African countries, *Dacus ciliatus* is widely distributed and occurs in Angola, Benin, Botswana, Burkina Faso, Cameroon, Chad, Democratic Republic of Congo, Malawi, Mozambique, Namibia, Niger, Nigeria, Côte d'Ivoire, Egypt, Ethiopia, Gabon, Ghana, Guinea, Kenya, Lesotho, Madagascar, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe (White and Elson Harris 1992) (Fig.1.G).

Impact

If uncontrolled, *D. ciliatus* causes high loss of yield but these losses are lower than those caused by *Bactrocera cucurbitae*, in areas where both species occur. *D. ciliatus* is a serious pest of cucurbit crops (Hancock, 1989). It is reported to cause important economic damage in some African countries where it has been occurred as in Egypt, South Africa (El Nahal et al., 1971 and Hancock, 1989). In the Reunion Island, *D. ciliatus*, together with *Dacus cucurbitae*, represent the major pests of Cucurbitaceae, having been reported in nine genera of this plant family (Dehecq, 1995; Vayssières et al., 2008).

Detection and Inspection

The efficacy of traps to detect the presence of this fruit fly is not proved. The male lure chemical used to attract male flies of pest species of *Dacus* and *Bactrocera* are not proven to be efficacy to attract *D. ciliatus* males making detection and monitoring more difficult. (Qureshi et al. ,1986). The males are not attracted to cue lure or vert lure (Hancock, 1985). Detection is therefore only possible by examination of fruit for female punctures and rearing the larvae in laboratory conditions to achieve the adult stage (EPPO, 2013). Food and based on food extract lures may be utilized to monitor both males and females (either protein hydrolysate or protein autolysate) (Sookar et al., 2001).

Phytosanitary Measures

It is recommended to program regular inspections on consignments of fruits imported from countries with reported presence of these pests. These inspections should be based on observing symptoms of infestation in fruits and cutting suspected infested ones in order to look for larvae. Cold treatment in transit or heat treatment may be conducted before the export of plant or plant products listed as host plants (EPPO, 2013).

In addition, Plants of host species transported with roots from countries where these pests occur should be free from soil, or the soil should be treated against puparia. The plants should not carry fruits. The importation of such plants may indeed be prohibited (USDA-APHIS, 2008).

Dacus punctatifrons, the Tomato fruit fly

Geographical distribution of *Dacus punctatifrons* showed that it is a species with a widely spread and has been recorded in several African countries including Angola, Botswana, Cameroon, Congo, Democratic Republic of Congo, Ethiopia, Benin, Côte d'Ivoire, Kenya, Liberia, Gabon, Ghana, Guinea, Malawi, Mozambique, Niger, Nigeria, South Africa, Uganda, Sierra Leone, Sudan, Tanzania, Togo, Zambia, Namibia, Burundi, Rwanda, Swaziland, Madagascar, and Zimbabwe (Fig.1. I), with a (possible) adventive population in Yemen as reported by White and Elson-Harris (1992); Mansell (2006); White and Goodger (2009) and De Meyer et al. (2015). In Cameroon, it is reported that *D. punctatifrons* has become a prominent pest on tomatoes where at times it causes the loss of whole crops due to heavy infestations by this fly (Tindo and Tamó 1999).

Dacus vertebratus, the jointed pumpkin fly

Geographical distribution

This species is a widespread fly in Africa and its preferable host plants are cucurbit fruits, it occurs in most Afro-tropical countries including, Angola, Botswana, Ethiopia, Ghana, Guinea, Kenya, Malawi, Mozambique, Nigeria, Senegal, South Africa, Sudan, Tanzania, Uganda, Côte d'Ivoire, Cameroon, Chad, Democratic Republic of Congo, Burkina Faso, Togo, Benin, Niger, Gabon, Madagascar, Namibia, Zambia, Zimbabwe, Gambia, Liberia, Mali, Burkina Faso, Gabon, Eritrea, Madagascar, Rwanda, Swaziland, Mayotte and Comoros Peninsula (De Meyer et al. 2015) (Fig.1. F).

Detection in inspection

The monitoring of this species is based on vert lure because it is not attracted to Cue-lure(White & Elson-Harris, 1992; Ekesi et al., 2006). However certain studies reported that one female of this species was captured with cue lure trap (De Meyer et al., 2012).

Ceratitis anonae, the anona fruit fly

Geographical distribution

Known as anona fruit fly, *Ceratitis anonae* is found many African countries : Central African Republic Cameroon, , Côte d'Ivoire, , Gabon, Ghana, Equatorial Guinea, Kenya, São Tomé and Príncipe, Guinea (Conakry), Mali, Nigeria, Togo, Tanzania, Democratic Republic of Congo and Uganda (White and Elson-Harris 1992; Copeland et al. 2006) (Fig.1. C).

Ceratitis rosa, the Natal fruit fly

Recent studies and new data led to distinguish two types of *C.rosa* that should be considered as two different species *C.rosa* and *C. quilicii*. This result has been pointed by recent integrative taxonomy

approaches using larval and adult morphology, wing morphometrics, cuticular hydrocarbons, pheromones, microsatellites, developmental physiology, geographical distribution, behavioral and chemo-ecological data. Initially, these two species were designated as two entities: 'R1', 'lowland' or 'hot rosa' corresponding to species *C. rosa*, and 'R2', 'highland' or 'cold rosa' corresponding to species *C. quilicii* (De Meyer et al. 2015) with varying distribution patterns. However, the two species can occur sympatrically in some regions (Malawi, South Africa, and Tanzania), but also show a disjunct distribution that appears to be correlated with temperature (Tanga et al. 2015). It is reported that many publications in the last years indicate *C. rosa* and were largely unable to differentiate between the two types of *C. rosa* as two different species although they could have likely been referring to, *C. quilicii*, or a mixture of the two. The current geographical distribution of the *C. quilicii* includes Botswana, Kenya, La Réunion, Malawi, Mauritius South Africa, Tanzania, and Zimbabwe. (De Meyer et al. 2015).

Geographical distribution

Ceratitis rosa is not highly invasive showing an only limited expansion of its distribution beyond its historical native range, which includes Angola, Ethiopia, Democratic Republic of Congo, Kenya, Malawi, Mali, Mauritius, Mozambique, Nigeria, Islands of Mauritius and La Réunion, Rwanda, Seychelles, Republic of South Africa (KwaZulu Natal), Swaziland, Tanzania, Uganda, Zambia, and Zimbabwe (White and Elson-Harris 1992; Copeland et al. 2006; De Villiers et al. 2013). In western Africa, there are no reliable records to be reported (De Meyer et al. 2015), although some authors have reported the pest in Côte d'Ivoire (N'depo et al. 2013) (Fig.1. J and K). However, the distribution range of *C. rosa* and *C. quilicii* remains non-exhaustive given that samples from many localities in the above-listed countries have not been assigned (De Meyer et al. 2015).

Impact

C. rosa is one of the most polyphagous species and it attacks several varieties and species of horticultural or wild fruits and vegetables. It can cause heavy losses to fruit crops and generate a negative economic impact on people's income. This indicates that it is a serious pest with phytosanitary concern.

Detection and Inspection

The monitoring of the species *Ceratitis rosa* can be conducted by traps baited with male lures similar to those used for *Ceratitis capitata*, and members of subgenera *Ceratitis* and *Pterandrus* in general. The main attractant used is trimedlure and terpinyl acetate, but not methyl eugenol or cue lure. The enriched ginger oil (EGO) lure has been tested and proved to be effective and more sensitive than trimedlure (Mwatawala et al., 2015; Manrakhan et al., 2017).

Phytosanitary Measures

In post-frontiers, consignments of listed host fruits from countries where *C. rosa* occurs should be subject to phytosanitary inspections based on observing fruit punctures and fruit cutting to look for larvae. It is recommended to avoid the import of fruits known to be hosts from an area where *C. rosa* presence is reported or limit this import to a place of production found free from the pest by regular inspection for 3 months before harvest. By analogy with *C. capitata*, countries with status "free" from *C. rosa* require fruits cold treatment in transit as a phytosanitary measure. For certain types of fruits, they may be treated by vapor heat. Plants or plant products species transported with roots from areas with *C. rosa* presence should be free from soil or must be treated against pupae or should be prohibited for acceding to countries with status "free" from *C. rosa*.

***Ceratitis cosyra*, the mango fruit fly**

Geographical distribution

It is one of the most important species of genera *Ceratitis*. It's widespread in Africa has been reported in many studies and its presence is confirmed in many countries of western Africa and in sub-Saharan countries Mozambique, Namibia, Nigeria, Sierra Leone, South Africa, Benin, Botswana, Central African Republic, Côte d'Ivoire, Democratic Republic of Congo, Guinea, Ghana, Kenya, Madagascar, Malawi, Mali, Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe, (Javaid 1986; White and Elson-Harris 1992; De Meyer 1998; Copeland et al. 2006; De Villiers et al. 2013) (Fig.1. L).

Impact

C. cosyra may present a high risk to horticultural crops, it is recorded from a limited range of plants, but it is the major fruit fly pest of mangoes in Kenya (Malio, 1979), Zambia (Javaid, 1986), Zimbabwe (Rendell et al., 1995) and some areas of South Africa (Labuschagne et al., 1996), while, in Côte d'Ivoire the highest rate of infestation was noted in guava orchards (N'Guetta, 1994).

Detection and Inspection

Studies carried out by hancock (1987) showed that males of *C. cosyra* are sometimes attracted to traps baited with terpineol acetate. Protein bait traps may be utilized to attract and monitor both sexes of *C. cosyra* (either protein hydrolysate or protein autolysate) but these traps are not selective to this species and collect large numbers of non-target insects including useful predators (Drew, 1982).

Phytosanitary measures

To avoid the introduction of this pest to countries with status "free" from *C. cosyra* phytosanitary measures should be taken. It is known that larvae may spread or be introduced to countries where this fly is absent by the pathway of infested fruits within commercial shipments or in the luggage of travellers. *C. rosa* is of quarantine significance for many lucrative markets like European countries and USA. Considerable scientific information is now available on the post-harvest control techniques of *C. cosyra* and many studies showed the effectiveness of heat treatment and cold storage to mitigate the risk of interception of live larvae in export shipments Grove et al. (1998).

Ceratitis ditissima

Citrus fruits are known to be a host fruit to this species and it showed high infestations levels in Citrus. This high infestation level that was exhibited by *C. ditissima* is attributed to the fact that it has a narrow host range and finds it difficult to find alternative hosts, making orange its preferred host. Billah (2014) confirmed that for *C. ditissima* it is very difficult to find alternative hosts which are why it is difficult to be displaced on citrus by another species.

It is localized mainly in West Africa, particularly Benin, Cameroon, Congo, Côte d'Ivoire, Ghana, Mali, Mozambique Nigeria, Uganda, and Zimbabwe (Vayssières et al. 2007; Foba et al. 2012; Aidoo et al. 2014) (Fig.1. M).

Ceratitis fasciventris

Geographical distribution

Ceratitis fasciventris occurs in Côte d'Ivoire, Democratic Republic of Congo, Mali, Ethiopia, Ghana, Equatorial Guinea, Kenya, Tanzania, Nigeria, São Tomé and Príncipe and Uganda (White and Elson-Harris 1992; Copeland et al. 2006). By comparison, *C. fasciventris* is distributed in many sub-Saharan countries but not outside of the continent. Molecular data suggest significant clustering and geographic differentiation within both *C. rosa* and *C. fasciventris* and rather complex genetic relationships among these two species and *Ceratitis anonae* Graham (Virgilio et al. 2013) (Fig.1. O).

Although there are two clusters for both *C. rosa* and *C. fasciventris*, the genetic divergence between conspecific groups is higher or comparable with that between heterospecific groups (Virgilio et al. 2013).

Detection and Inspection

The monitoring of the species *Ceratitis fasciventris* (Bezzi) may be conducted by traps baited with male lures similar to those used for *Ceratitis capitata* species, and members of subgenera *Ceratitis* and *Pterandrus* in general. In a study on fruit flies conducted in mango trees in Mali, *Ceratitis fasciventris* (Bezzi), Manrakhan and Lux (2008) demonstrated that, for both males and females, the nutritional effect was more important than mating status in influencing the attraction response to food odors. Compared with *Ceratitis capitata*, *Ceratitis fasciventris* had a lower response to food odors both for protein-deprived virgin females and males (Manrakhan and Lux 2008).

Several studies showed that there is a high similarity between different members of the *Ceratitis* complex (*Ceratitis fasciventris* (Bezzi), *C. anonae* Graham, and *C. rosa* Karsch) in Africa. It remains difficult to separate these three species based on morphological and molecular criteria (Delatte et al. 2013). However, they have different distributions, pest status, host ranges, and host preferences (Copeland et al. 2006).

Phytosanitary Measures

The phytosanitary measures to be taken are similar to those adopted for *Ceratitis capitata* and *C.rosa* in exported consignments.

Ceratitis silvestrii

The main host fruit of *C. silvestrii* is mango mainly in several countries of Western Africa, it is found co-existing with *C. quinaria* (Sawadogo et al.2013).

Geographical distribution

Ceratitis silvestrii has been reported as pest insect of mango in Nigeria, Burkina Faso, Senegal, Mali, and Niger (Vayssières et al. 2005).Furthermore, new studies showed that this species is attacking mango orchards or isolated trees in several countries of West Africa, and co-exist with *C. quinaria* (Ouedraogo et al. 2010; Sawadogo et al. 2013). Its activity is higher during the season with low relative humidity when it attacks early-maturing mango cultivars and causes high damage (Vayssières et al. 2005; Vayssières et al. 2009) (Fig.1. N). Two studies carried out in 2007 and 2015 years respectively showed that In Mali, 7.28 % of fruit flies reared from mango were *C. silvestrii* (Vayssières et al. 2007) and in Benin 2.77 % of fruit flies were *C. silvestrii* (Vayssières et al. 2015).

Phytosanitary measures

According to CABI (2018), the introduction of fruit flies is usually occurring accidentally by the importation of infested fruit, either with consignments or in the luggage of passengers. However, Adults do not fly long distances and are not responsible for the introduction of new species to new areas. To avoid introduction, the regular inspections should be conducted on consignment, cargo, and passenger baggage.

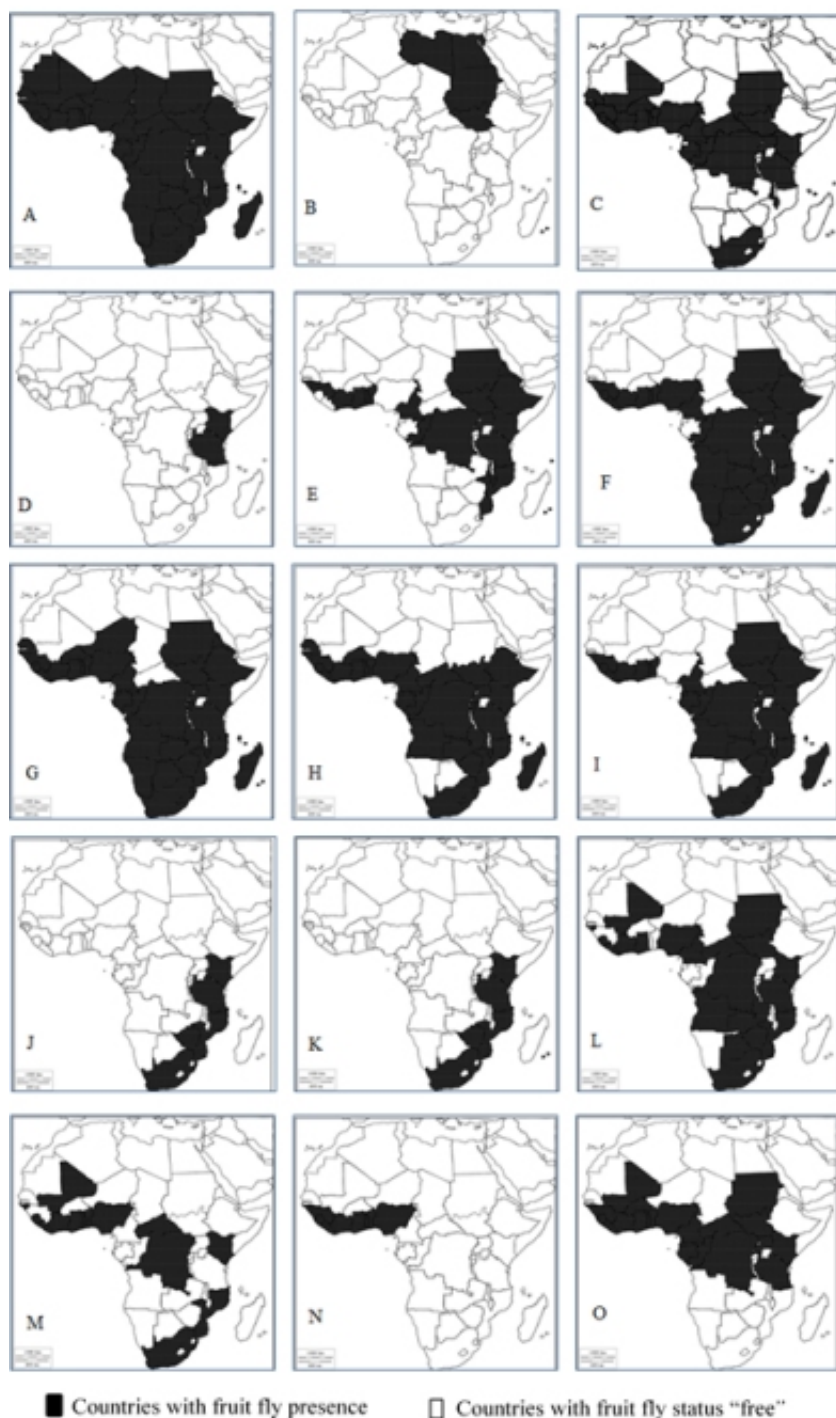


Figure 1: Maps of distribution in Africa of main fruit flies species being of biosecurity concern to Morocco. (A) *B. dorsalis* ; (B) *B. zonata*; (C) *C. Anonae*; (D) *D. latifrons* ; (E) *Z. cucurbitae* ; (F) *D. vertebratus*; (G) *D. ciliatus* ; (H) *D. bivittatus*; (I) *D. punctatifrons*; (J) *C. rosa*; (K) *C. quilicii* (L) *C. cosyra*; (M) *C. ditissima*; (N) *C. silvestrii*; (O) *C. fasciventris*. (Maps conceived the authors basing on data collected from EPPO, CABI and EOL databases).

OTHER SPECIES WITHIN GENERA CERATITIS WITH ECONOMIC IMPORTANCE

Ceratitis catairii

C. catairii is a species which is not abundant and occurs at low scale but it has been reported in

Mauritius, La Réunion and Seychelles (Duyck et al. 2004).

Ceratitis flexuosa

Based on data obtained from Known occurrences, collected specimens and observations of *Ceratitis flexuosa* (Walker 1853), this species have been described by the past as *C. capitata*, it represents a high level of morphological similarity with species of *Ceratitis* Complex and it occurs in Angola, Cameroon, Congo (D.R), Côte d'Ivoire, Ghana, Guinea, Kenya, Niger, Nigeria, Tanzania, Togo, Uganda (EOL, 2020).

Ceratitis punctata

This species is found in Cameroon, Congo, Democratic Republic of Congo, Côte d'Ivoire, Guinea, Kenya, Rwanda, Senegal, South Africa Tanzania, Uganda, Zambia, and Zimbabwe (De Meyer 2000).

Ceratitis quinaria, the five-spotted fruit fly

Ceratitis quinaria occurs widely during the dry season causing damage to early maturing fruits and is distributed in West Africa and abundant in mango orchards (Vayssières et al. 2005; 2007; 2009; 2011). There is a positive relationship between high temperature, relative humidity and rainfall with *C. quinaria* populations (Vayssières et al. 2005). Countries with established infestations of *C. quinaria* include Benin, Botswana, Burkina Faso, Côte d'Ivoire, Guinea, Ghana, Namibia, Malawi, Mali, Senegal, South Africa, Sudan, Togo, Yemen and Zimbabwe (Hancock et al. 2001; White and Elson-Harris 1992; De Meyer 1998; De Meyer et al. 2002; Vayssières et al. 2005). This fruit fly had a heavy economic impact to crops.

Host plants present in Morocco of fruit flies reported in Africa

Morocco has a rich biodiversity of wild and cultivated plants. Several plant species present in Morocco can constitute host plants for fruit flies. Table 1 presents the main plant families and species and their status in relation to the main fruit flies cited in this review.

CONCLUSION

Biosecurity issues make the study of fruit flies a strategic choice to ensure the protection of territories not yet conquered by these polyphagous pests. Decision-makers are strongly urged to establish phytosanitary measures, surveillance, identification, and control plans for fruit flies to reduce their economic impact on yields and limit restrictions linked to phytosanitary contingencies. Worldwide, Studies on fruit flies continue to increase and provide useful and practical knowledge to those working in the areas of monitoring and control tactics. From the 1950s to the present day, there has been an emphasis on chemical control research, especially the use of baits (Conway and Forrester, 2011; Díaz-Fleischer et al., 2017; Steiner, 1952). However, the continued use of insecticides is increasingly limited, making it necessary to evaluate other control strategies for inclusion in fruit fly management. The workers on tephritidae should have all current information about biology, distribution, and pest risk analysis to provide work tools and worksheets helping them mitigate the risk of introduction of fruit flies into their territory. Morocco is called to mobilize all scientific, regulative, and technical tools to provide operational actions to avoid an eventual introduction of potential invasive fruit flies with high risk on Moroccan biosecurity. High attention should be oriented to the plants intended for planting imported from African countries. Although it might seem a good opportunity, importing plants with a questionable origin or doubtful phytosanitary certificate might have a severe economic impact on the fruit-growing areas of Morocco. Considering that many alien invasive polyphagous fruit flies start producing severe

damages in many European countries and the USA and the recent climate changes, we recommend a thorough monitoring program and a detailed pest sheet biology identification and surveillance program.

REFERENCES

Agarwal M.L., Rahman S., Yazdani S. S. (1995). Trapping of *Dacus* (*Bactrocera*) *zonatus* (Saunders) (Diptera:Tephritidae) in different trap systems in north Bihar. *Shashpa*, 2:80-81.

Aluja M., Pérez-Staples D., Macías-Ordóñez R., Piñero J., Mcpherson B., Hernández-Ortiz V.(2003). Nonhost status of *Citrus sinensis* cultivar Valencia and *C. paradisi* cultivar Ruby Red to Mexican *Anastrepha fraterculus* (Diptera: Tephritidae). *J Econ Entomol.* 96(6):1693-703.

APHIS (Animal and Plant Inspection Service). (2016). APHIS prohibits the importation of certain citrus fruits from Morocco due to Mediterranean fruit fly https://www.aphis.usda.gov/import_export/plants/plant_imports/federal_order/downloads/2016/2016-10.pdf.

Armstrong J. W., Couey H.M.(1989). Control; fruit disinfestation; fumigation, heat and cold. In: Robinson AS, Hooper G, eds. *Fruit Flies; their Biology, Natural Enemies and Control*. World Crop Pests. Amsterdam, Netherlands: Elsevier, 3(B):411-424

Baker R. T., Cowley J. M. (1991). A New Zealand view of quarantine security with special reference to fruit flies. In: *First International Symposium on Fruit Flies in the Tropics*, Kuala Lumpur, 1988, [ed. by Vijayasegaran S, Ibrahim AG]. Kuala Lumpur, Malaysia: Malaysian Agricultural Research and Development Institute. 396-408.

Bezzi, M. (1908). *Diagnoses: D'especes Nouvelles de Dipteres D'afrique*

Billah M. K., Adom K., Osae M.Y., Jiang J., Du J. (2014). Evaluation of The Great® Fruit Fly Bait (GFFB) against fruit flies in two mango-production zones in Ghana. Final Technical Report (Submitted to the Environmental Protection Agency, EPA – Ghana), 19 pp.

CABI. (2018). *Invasive species compendium*. CAB International, Wallingford. Available:<http://cabi.org/isc/datasheet>. (January 2018).

Cantrell, B. K., Cahill, A., & Chadwick, B. (2002). *Fruit fly fighters: eradication of the papaya fruit fly* (No. 81). CSIRO PUBLISHING.

Carroll L. E., White I. M., Freidberg A., Norrbom A. L., Dallwitz M. J., Thompson F. C. (2002). *Pest fruit flies of the world*. Version: 8th December 2006. <http://delta-intkey.com/ffa/> CBI (2005) EU Market survey: fresh fruit and vegetables, compiled for CBI by ProFound, Netherlands, pp 172.

Conway H. E., & Thomas F. O. (2011). Efficacy of ground spray application of bait sprays with malathion or spinosad on Mexican fruit fly (Diptera: Tephritidae) in Texas citrus. *Journal of economic entomology*, 104(2), 452-458.

Copeland R. S., Wharton R. A., Luke Q., De Meyer M., Lux S., Zenz N., Machera P., Okumu M. (2006). Geographic distribution, host fruit and parasitoids of African fruit fly pests *Ceratitis ananæ*, *Ceratitis cosyra*, *Ceratitis fasciventris*, and *Ceratitis rosa* (Diptera: Tephritidae) in Kenya. *Annals Entomol Soc Am* 99:261-278.

Correia A. R. I., Rego J. M., Olmi M. (2008). A pest of significant economic importance detected for the first time in Mozambique: *Bactrocera dorsalis* Drew, Tsuruta & White (Diptera: Tephritidae: Dacinae). *Boll Zool Agraria Bachicol, Serie II* 40:9-13.

Culliney, T. W. (2002). The aliens have landed: invasive species threaten Hawaii agriculture. *Agriculture Hawaii*, 3(1), 6-9.

De Meyer M, Mohamed S, White IM (2007) Invasive fruit fly pests in Africa. Tervuren, Belgium, Royal Museum for Central Africa. <http://www.africamuseum.be/fruitfly/AfroAsia.htm>. Accessed 28 May 2016

De Meyer M, Robertson MP, Peterson AT, Mansell MW (2008) Ecological niches and potential geographical distributions of Mediterranean fruit fly (*Ceratitis capitata*) and Natal fruit fly (*Ceratitis rosa*). *J Biogeog* 35:270–281

De Meyer M. (1998). Revision of the subgenus *Ceratitis* (*Ceratalaspis*) Hancock (Diptera:Tephritidae). *Bull Entomol Res* 88:257–290.

De Meyer M. (2000). Systematic revision of the subgenus *Ceratitis* MacLeay s.s. (Diptera,Tephritidae). *Zool J Linn Soc* 128:439–467.

De Meyer M., Copeland R. S., Lux S. A., Mansell M., Quilici S., Wharton R., White I. M., Zenz N. J. (2002). Annotated check list of host plants for afrotropical fruit flies (Diptera: Tephritidae) of the genus *Ceratitis*. *Documentation Zoologique, Musée Royal de l'Afrique Centrale*, 27: 1 – 91.

De Meyer M., Delatte M. H., Mwatawala M., Quilici S., Vayssières J. F., Virgilio M. (2015). A review of the current knowledge on *Zeugodacus cucurbitae* (Coquillett) (Diptera, Tephritidae) in Africa, with a list of species included in *Zeugodacus*. *ZooKeys* 540:539–557

De Villiers M, Manrakhan A, Addison P, Hattingh V (2013) The distribution, relative abundance, and seasonal phenology of *Ceratitis capitata*, *Ceratitis rosa*, and *Ceratitis cosyra* (Diptera:Tephritidae) in South Africa. *Environ Entomol* 42:831–840

Dehecq, J. S. (1995). Etude de la communication pheromonale chez trois thephritidae de la Reunion: *Dacus ciliatus* Loew, *Dacus demmerezi* (Bezzi) et *Trirhithromya cyanescens* (Bezzi) (Doctoral dissertation, Thesis (Certificat d'Etudes Superieures Agronomiques). Ecole Nationale Supérieure Agronomique de Montpellier, France).

Delatte H, Virgilio M, Simiand C, Quilici S, Meyer M (2013) Isolation and characterisation of sixteen microsatellite markers cross-amplifying in a complex of three African agricultural pests (*Ceratitis rosa*, *C. anonae* and *C. fasciventris*, Diptera: Tephritidae). *Con Genet Res* 5:31–34.

Dhami, M.K., Gunawardana, D.N., Voice, D., Kumarasinghe, L., 2016. A real-time PCR toolbox for accurate identification of invasive fruit fly species. *J. Appl. Entomol.* 140, 536–552. <https://doi.org/10.1111/jen.12286>.

Díaz-Fleischer F., Pérez-Staples D., Cabrera-Mireles H., Montoya P., & Liedo P. (2017). Novel insecticides and bait stations for the control of *Anastrepha* fruit flies in mango orchards. *Journal of Pest Science*, 90(3), 865-872.

Drew R. A. I. (1994). The *Bactrocera dorsalis* complex of fruit flies (Diptera: Tephritidae: Dacinae) in Asia. *Bull Entomol Res Suppl Ser Suppl* 2:68.

Drew R. A. I. , Tsuruta K., White I. M. (2005). A new species of pest fruit fly (Diptera: Tephritidae: Dacinae) from Sri Lanka and Africa. *Afri Entomol* 13:149–154

Drew R. A. I., Hooper G. H. S., Bateman M. A. (1982). Economic fruit flies of the South Pacific region. Queensland Department of Primary Industries, Brisbane, p 139

- Drew R. A. I., Romig M. C. (2013). Tropical fruit flies of South-East Asia: (Tephritidae: Dacinae). CABI, Wallingford, 653 pp.
- Duyck P. F., David P., Quilici S. (2004). A review of relationships between interspecific competition and invasions in fruit flies (Diptera: Tephritidae). *Ecol Entomol* 29:511-520.
- Ekesi S., De Meyer M., Mohamed S. A., Virgilio M., Borgemeister C. (2016). Taxonomy, ecology and management of native and exotic fruit fly species in Africa. *Ann Rev Entomol* 61:219-238.
- Ekesi S., Nderitu P. W., Rwomushana I. (2006). Field infestation, life history and demographic parameters of *Bactrocera dorsalis* Drew, Tsuruta & White, a new invasive fruit fly species in Africa. *Bull Entomol Res* 96:379-386.
- Ekesi S., Nderitu P. W., Rwomushana I. (2006). Field infestation, life story and demographic parameters of the fruit flies *Bactrocera invadens* (Diptera: Tephritidae) in Africa. *Bulletin of Entomological Research*, 96: 379-386.
- Elaini R, Mazih A (2018) Current status and future prospects of *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) control in Morocco. *J. Entomol.*, 15: 47-55.
- Elith, J., H. Graham, C., P. Anderson, R., Dudík, M., Ferrier, S., Guisan, A. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, 29(2), 129-151.
- Elnagar S., El-Sheikh M., Hashem A., Afia Y. (2010). Recent invasion by *Bactrocera zonata* (Saunders) as a new pest competing with *Ceratitis capitata* (Wiedemann) in attacking fruits in Egypt. *J Appl Biol* 104:97-102.
- El-Samea S. A. A., Fetoh B. E. A. (2006). New record of *Bactrocera zonata* (Saunders) (Diptera: Tephritidae) on potatoes in Egypt. *Egypt J Agric Res* 84:61-63
- EOL. (2020). (Encyclopedia Of Life) Available in <https://eol.org/pages/724059> visited in April, 26th. 2020.
- EPPO. (2013). European and Mediterranean Plant Protection Organization. *Bulletin OEPP* 43:417-424. ISSN 0250-8052. doi:10.1111/epp.12059.
- Foba C. N., Afreh-Nuamah K., Billah M. K., Obeng-Ofori D. (2012). Species composition of fruit flies (Diptera: Tephritidae) in the citrus museum at the Agricultural Research Centre (ARC), Kade, Ghana. *Int J Trop Insect Sci* 32:12-23.
- Goergen G., Vayssières J. F., Gnanvossou D., Tindo M. (2011). *Bactrocera dorsalis* (Diptera: Tephritidae), a new invasive fruit fly pest for the Afrotropical region: host plant range and distribution in West and Central Africa. *Environ Entomol* 40:844-854.
- Grove T., De Beer M. S., Dreyer S., Steyn W. P. (1998). Monitoring fruit flies in avocado orchards. *S Afr Avocado Growers' Assoc Yearb* 21:80-82.
- Hala, N., Quilici, S., Gnago, A. J., N'Depo, O. R., N'Da Adopo, A., Kouassi, P., & Allou, K. (2008). Status of fruit flies (Diptera: Tephritidae) in Côte d'Ivoire and implications for mango exports. In *Fruit Flies of Economic Importance to Applied Knowledge. Proceedings of the 7th International Symposium on Fruit Flies of Economic Importance*, 10-15 September 2006, Salvador, Brazil (pp. 233-239). Biofábrica Moscamed Brasil, SBPC.
- Hancock D. L. (1985). New species and records of African Dacinae (Diptera: Tephritidae). *Arnoldia, Zimbabwe*, 9(22):299-314.

- Hancock D. L.(1989). Southern Africa. In: Fruit Flies: Their biology, natural enemies and control, World Crop Pests, 3A [ed. by Robinson AS, Hooper G,] Amsterdam, The Netherlands : Elsevier Science Publishers B.V., 51-58.
- Hancock D. L., Kirk-Spriggs A. H., Marais E. (2001). An annotated checklist and provisional atlas of Namibian Tephritidae (Diptera: Schizophora). Cimbebasia 17:41-72.
- Hendrichs, J. (1996). Action programs against fruit flies of economic importance: session overview.
- Hussain M. A., Haile A., Ahmad T. (2015). Infestation of two tephritid fruit flies, *Bactrocera dorsalis* (syn. *B. invadens*) and *Ceratitis capitata*, in guava fruits from selected regions of Eritrea. Afr Entomol 23:510-513.
- Ibrahim Ali S. A., Mahmoud M. E. E., Man-Qun W., Mandiana D. M. (2013). Survey and monitoring of some Tephritidae of fruit trees and their host range in River Nile State, Sudan. Pers Gulf Crop Prot 2:32-39.
- Isabirye B. E., Akol A. M., Mayamba A., Nankinga C. K., Rwomushana I. (2015). Species composition and community structure of fruit flies (Diptera: Tephritidae) across major mango-growing regions in Uganda. Int J Trop Insect Sci 35:69-79.
- Jacquard C., Virgilio M., Quilici S., De Meyer M., Delatte H. (2013). Population structuring of an economic important pest: the case of the fruit fly *Bactrocera cucurbitae* on the tropical island of La Réunion. Biol Invasions 15:759-773.
- Jang E. B., Nagata J. T., Chan H. T., Laidlaw W. G.(1999). Thermal death kinetics in eggs and larvae of *Bactrocera latifrons* (Diptera: Tephritidae) and comparative thermotolerance to three other tephritid fruit fly species in Hawaii. Journal of Economic Entomology, 92(3):684-690; 37.
- Javaid I. (1986). Causes of damage to some wild mango fruit trees in Zambia. Int Pest Control 28:98-99.
- Kapoor V. C. (1993). Indian fruit flies (Insecta: Diptera: Tephritidae). Oxford and IBH Publishing Company, New Delhi. 228 pp.
- Karsch, F. (1887). *Acrosoma Stübels*, nov. spec. Berliner entomologische Zeitschrift, 30(2), 340-340.
- Kiritani, K. (1998). Exotic insects in Japan. Entomological Science, 1(3), 291-298.
- Labuschagne T., Brink T., Steyn W. P., Beer M. S. (1996). Fruit flies attacking mangoes - their importance and post-harvest control. Yearbook - South African Mango Growers' Association, 16:17-19; 5.
- Liquido N. J., Harris E. J. Dekker L. A. (1994). Ecology of *Bactrocera latifrons* (Diptera: Tephritidae) populations: host plants, natural enemies, distribution and abundance. Anns Entomol Soc Am 87:71-84.
- Lux S. A., Copeland R. S., White I. M., Manrakhan A., Billah M. K. (2003). A new invasive fruit fly species from the *Bactrocera dorsalis* (Hendel) group detected in east Africa. Insect Sci Appl 3:355-361.
- Malio E. (1979). Observations on the mango fruit fly *Ceratitis cosyra* in the Coast Province, Kenya. Kenya Entomologist's Newsletter, No. 10:7.
- Manrakhan, A. H. J. H., Hattingh, V., Venter, J. H., & Holtzhausen, M. (2011). Eradication of

Bactrocera invadens (Diptera: Tephritidae) in Limpopo Province, South Africa. *African Entomology*, 19(3), 650-659.

Manrakhan, A., Daneel, J. H., Beck, R., Virgilio, M., Meganck, K., & De Meyer, M. (2017). Efficacy of trapping systems for monitoring of Afrotropical fruit flies. *Journal of applied entomology*, 141(10), 825-840.

Mansell M. (2006). Preliminary report on a visit to Madagascar to evaluate trap catches from a survey of fruit flies (Diptera: Tephritidae) possibly associated with litchis. Unpublished USDA APHIS Report, 3 pp.

Massebo, F., & Tefera, Z. (2015). Status of *Bactrocera invadens* (Diptera: Tephritidae) in Mango-Producing Areas of Arba Minch, Southwestern Ethiopia. *Journal of Insect Science*, 15(1).

Merow, C., Smith, M. J., & Silander Jr, J. A. (2013). A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography*, 36(10), 1058-1069.

Mwatawala M. W., De Meyer M., Makundi R. H., Maerere A. P. (2006b). Seasonality and host utilization of the invasive fruit fly, *Bactrocera invadens* (Diptera: Tephritidae) in central Tanzania, *J. Appl. Entomol.*, 130: 530-537.

Mwatawala M. W., De Meyer M., Makundi R. H., Maerere A. P. (2009). Host range and distribution of fruit-infesting pestiferous fruit flies (Diptera, Tephritidae) in selected areas of Central Tanzania. *Bulletin of Entomological Research*, doi:10.1017/S0007485309006695.

Mwatawala M. W., De Meyer M., Makundi R.H., Maerere A. P. (2006a). Biodiversity of fruit flies (Diptera, Tephritidae) in orchards in different agro-ecological zones of the Morogoro region, Tanzania. *Fruits*, 61: 321-332.

Mwatawala M. W., De Meyer M., White I. M., Maerere A., Makundi R. H. (2007). Detection of the solanum fruit fly, *Bactrocera latifrons* (Hendel) in Tanzania (Dipt., Tephritidae). *J Appl Entomol* 131:501-503.

Mwatawala M. W., Virgilio M., Joseph J., De Meyer M. (2015). Niche partitioning among two *Ceratitis rosa* morphotypes and other *Ceratitis* pest species (Diptera, Tephritidae) along an altitudinal transect in Central Tanzania. *ZooKeys* 540:429-442.

Mwatawala M. W., White I. M., Maerere A.P., Senkondo F.J., De Meyer M. (2004). A new invasive *Bactrocera* species (Diptera; Tephritidae) in Tanzania. *Afr Entomol* 12:154-156.

Mwatawala M.W., Maerere A. P., Makund R., De Meyer M. (2010). Incidence and host range of the melon fruit fly *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae) in Central Tanzania. *Int J Pest Man* 56:265-273.

Mziray H. A., Makundi R. H., Mwatawala M., Maerere A., De Meyer M. (2010). Host use of *Bactrocera latifrons*, a new invasive tephritid species in Tanzania. *J Econ Entomol* 103:70-76.

N'depo O. S, Hala N., N'da Adopo A., Coulibaly F., Kouassi K. P., Vayssières J. F, De Meyer M. (2013). Fruit flies (Diptera: Tephritidae) populations dynamic in mangoes production zone of Côte d'Ivoire. *Agric Sci Res J* 3:352-363.

N'Guetta K. (1994). Inventory of insect fruit pests in northern Cote d'Ivoire. *Fruits* (Paris), 49(5/6):430-431, 502-503.

Nishida, R., & Tan, K. H. (2014). Search for new fruit fly attractants from plants: a review. In Proceedings, 9th International Symposium on Fruit Flies of Economic Importance (Vol. 12).

Ouedraogo S. N., Vayssières J. F., Dabiré A. R., Rouland-Lefèvre C. (2010). Fruitiers locaux hôtes des mouches de fruits (Diptera: Tephritidae) inféodées aux manguiers dans l'ouest du Burkina Faso: identification et taux d'infestation/Wild fruit crops as hosts of mango fruit flies (Diptera: Tephritidae) in western Burkina Faso: identification and infestation rates (in French). *Cereal Sci Bo* 4:36-41.

Papadopoulos N., Plant R. E., Carey J. R. (2013). From trickle to flood: the large-scale, cryptic invasion of California by tropical fruit flies. *Proc Roy Soc B* 280. doi:10.1098/rspb.2013.1466.

Quilici S., Duyck P. F., Rousse P., Gourdon F., Simiand C., Franck A. (2005). La mouche de la pêche sur mangue, goyave, etc. A La Réunion, évolution des recherches et des méthodes de lutte. *Phytoma* 584:44-47.

Qureshi Z. A, Siddiqui Q. H, Hussain T. (1986). Screening of lures for Ethiopian melon fly. In: Fruit flies: Proceedings of the 2nd International Symposium [ed. by Economopoulos AP] USA: Elsevier Science Publ, 463-467.

Qureshi Z. A., Siddiqui Q. H., Hussain T. (1992). Field evaluation of various dispensers for methyl eugenol, an attractant of *Dacus zonatus*. *Journal of Applied Entomology* 113, 365-367.

Rendell C.H., Mwashayenyi E., Banga D. J. (1995). The mango fruit fly: population and varietal susceptibility studies. *Zimbabwe Science News*, 29(1):12-14; 2.

Retamales, J. B., Sepúlveda, J. C. (2011). Fruit production in Chile: bright past, uncertain future. *Rev. Bras. Frutic.* 33, 173-178. <https://doi.org/10.1590/S0100-29452011000500020>.

Rwomushana I., Ekesi S., Gordon I., Ogol C. K. P. O. (2008). Host plants and host preference studies for *Bactrocera dorsalis* (Diptera: Tephritidae) in Kenya, a new invasive fruit fly species in Africa. *Ann Entomol Soc Am* 101:331-340.

Saafan M. H., Foda S.M., Abdel-Hafez T.A. (2005). Ecological studies on Mediterranean fruit fly, *Ceratitis capitata* (Wied.) and peach fruit fly, *Bactrocera zonata* (Saund.) in apricot orchards. *Egypt J Agric Res* 83:928-934.

Sarwar, M. (2015). Cultural measures as management option against fruit flies pest (Tephritidae: Diptera) in garden or farm and territories. *International Journal of Animal Biology*, 1(5), 165-171.

Sawadogo A, Gnankine O, Badolo A, Ouedraogo A, Ouedraogo S, Dabiré R, Sanon A (2013) First report of the fruits flies, *Ceratitis quinaria* and *Ceratitis silvestri*, on yellow plum *Ximenia americana* in Burkina Faso, West Africa. *The Open Ent J* 7:9-15.

Schutze M. K., Mahmood K., Pavasovic A., Bo W., Newman J., Clarke A. R., Krosch M. N., Cameron S. L. (2015). One and the same: integrative taxonomic evidence that *Bactrocera dorsalis* (Diptera: Tephritidae) is the same species as the Oriental fruit fly *Bactrocera dorsalis*. *Syst Entomol* 40:472-486.

Seewooruthun, S. I., Permilloo, S., Sookar, P., & Soonnoo, A. R. (2000). The oriental fruit fly, *Bactrocera dorsalis* eradicated from Mauritius. In Proceedings of the Indian Ocean Commission, Regional Fruit Fly Symposium, Flic en Flac, Mauritius, 5th-9th June, 2000 (pp. 207-210). Indian Ocean Commission.

Shehata N. F., Younes M. W. F., Mahmoud Y. A. (2008). Biological studies on the peach fruit fly,

Bactrocera zonata (Saunders). Egypt J Appl Sci Res 4:1103-1106.

Shimizu Y., Kohama T., Uesato T., Matsuyama T., Yamagichi M. (2006). Invasion of solanum fruit fly *Bactrocera latifrons* (Diptera: Tephritidae) to Yomaguni Island, Okinawa Prefecture, Japan. Appl Entomol Zool 42:269-275.

Siddiqui, Q. U. H., Ahmad, N., Rashdi, S. S., Niazi, S., Drew, R. A. J., Ghouri, A. S. K., ... & Harris, E. J. (2000). Integrated management of fruit fly *Dacus zonata* (Saunders). Asian Journal of Plant Sciences, 2(2), pp-89.

Sookar P., Alleck M., Buldawoo I., Khayrattee F. B., Choolun T., Permalloo S., Rambhunjun M. (2012). Area-wide management of the melon fly *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae). In: Deguine JP (ed) Actes du séminaire international de clôture Gamour, SaintPierre, La Réunion, 21-24 Nov 2011, pp 98-102.

Sookar P., Seewooruthun S. I., Khayratee F. (2001). Assessment of protein baits for the monitoring and control of fruit flies (Diptera: Tephritidae). Revue Agricole et Sucrière de l'Île Maurice, 80/81(3-1/3):287-294.

Sookar, P., Seewooruthun, S. I., & Khayratee, F. (2001). Assessment of protein baits for the monitoring and control of fruit flies (Diptera: Tephritidae). Revue Agricole et Sucrière de l'Île Maurice, (3-1/3), 287-294.

Srivastava K. P., Butani D. K. (2009). Pest management in vegetables, p. 380. Studium Press (India) PVT. LMT.

Steiner L. F. (1952). Fruit fly control in Hawaii with poison-bait sprays containing protein hydrolysates. Journal of Economic Entomology, 45(5), 838-843.

Stonehouse J. M., Singh H. S., Patel R. K., Satpathy S., Shivalingaswamy T. M., Shivalingaswamy S., Rai S., Verghese A., Mumford J. D. (2007). The measurement and modelling of losses of cucurbits to tephritid fruit flies. Commun. Biometry Crop Sci. 2: 17-25.

Tanga C. M., Manrakhan A., Daneel J. H., Mohamed S.A., Fathiya K., Ekesi S. (2015). Comparative analysis of development and survival of two Natal fruit fly *Ceratitis rosa* Karsch (Diptera, Tephritidae) populations from Kenya and South Africa. ZooKeys 540:467-487. doi:10.3897/zookeys.540.9906. <http://zookeys.pensoft.net>

Tindo M., Tamò M. (1999). Mouche de fruit (*Dacus punctatifrons*: Diptera, Tephritidae) comme problème de production de la tomate dans la région de la Lekie (Sud-Cameroun). Annales Soc. Entomol. France, 35: 525-527.

USDA-APHIS., (2008). Federal import quarantine order for host materials of *Bactrocera invadens* (Diptera: Tephritidae), invasive fruit fly species. USDA-APHIS, Riverdale, Maryland, USA.

Vargas R. I., Leblanc L., Putoa R., Eitam A. (2007). Impact of introduction of *Bactrocera dorsalis* (Diptera: Tephritidae) and classical biological control releases of *Fopius arisanus* (Hymenoptera: Braconidae) on economically important fruit flies in French Polynesia. J Econ Entomol 100:670-679.

Vargas R. I., Piñero J. C., Leblanc L. (2015). An overview of pest species of *Bactrocera* fruit flies (Diptera: Tephritidae) and the integration of biopesticides with other biological approaches for their management with a focus on the Pacific Region. Insects 6:297-318.

Vayssières J. F., Carel Y. (1999). Les Dacini (Diptera: Tephritidae) inféodées aux Cucurbitaceae à la Réunion: gamme de plantes hôtes et stades phénologiques préférentiels des fruits au moment de la

piqûre pour des espèces cultivées. *Ann Soc Entom France* 35:197-202.

Vayssières J. F., Goergen G., Lokossou O., Dossa P., Akponon C. (2005). A new *Bactrocera* species in Benin among mango fruit fly (Diptera: Tephritidae) species. *Fruits* 60:371-377.

Vayssières J. F., Goergen G., Lokossou O., Dossa P., Akponon C. (2005). A new *Bactrocera* species in Benin among mango fruit fly (Diptera: Tephritidae) species. *Fruits*, 60: 371-377.

Vayssières J. F., Kalabane S. (2000). Inventory and fluctuations of the catches of (Diptera: Tephritidae) associated with mangoes in Coastal Guinea. *Fruits* 55: 259-270.

Vayssières J. F., Kalabane S. (2000). Inventory and fluctuations of the catches of Diptera Tephritidae associated with mangoes in Coastal Guinea. *Fruits*, 55: 259-270.

Vayssières J. F., Korie S., Ayegnon D. (2009). Correlation of fruit fly (Diptera Tephritidae) infestation of major mango cultivars in Borgou (Benin) with abiotic and biotic factors and assessment of damage. *Crop Protection*, 28: 477-488.

Vayssières J. F., Korie S., Coulibaly T., Temple L., Boueyi S. (2008). The mango tree in northern Benin (1): cultivar inventory, yield assessment, early infested stages and loss due to fruit flies (Diptera Tephritidae). *Fruits*, 63: 335- 348.

Vayssières J. F., Sanogo F., Noussourou M. (2007). Inventory of the fruit fly species (Diptera: Tephritidae) linked to the mango tree in Mali, and tests of integrated control. *Fruits* 62:329-341.

Vayssières J. F., Sinzogan A., Adandonon A., Rey J. Y., Dieng E. O., Camara K., Sangaré M., Ouedraogo S., Sidibé A., Keita Y., Gogovor G. (2014). Annual population dynamics of mango fruit flies (Diptera: Tephritidae) in West Africa: socio-economic aspects, host phenology and implications for management. *Fruits* 69:207-222.

Vayssières J. F., Vannière G. P. S., Barry O., Hanne A. M., Niassy A., Ndiaye M., Delhove G., Korie S. (2011). Preliminary inventory of fruit fly species (Diptera, Tephritidae) in mango orchards in the Niayes region, Senegal, in 2004. *Fruits* 66:91-107.

Vayssières J.F, De Meyer M., Ouagoussounon I., Sinzogan A., Adandonon A., Korie S., Wargui R., Anato F., Hounbo H., Didier C., De Bon H., Goergen G. (2015). Seasonal abundance of mango fruit flies (Diptera: Tephritidae) and ecological implications for their management in mango and cashew orchards in Benin (Centre & North). *J Econ Entomol*. doi:10.1093/jee/tov143.

Virgilio M., Backeljau T., Emeleme R., Juakali J., De Meyer M. (2011). A quantitative comparison of frugivorous tephritids (Diptera: Tephritidae) in tropical forests and rural areas of the Democratic Republic of Congo. *Bull Entomol Res* 101:591-597.

Virgilio M., Delatte H., Quilici S., Backeljau T., De Meyer M. (2013). Cryptic diversity and gene flow among three African agricultural pests: *Ceratitis rosa*, *Ceratitis fasciventris* and *Ceratitis anonae* (Diptera, Tephritidae). *Mol Ecol* 22:2526-2539.

Weems H. V. (1966). Natal fruit fly (*Ceratitis rosa* Karsch) (Diptera: Tephritidae). Florida Department of Agriculture and Consumer Services, Division of Plant Industry, Entomology Circular No.51, 2 pp.

White I. M. (2006). Taxonomy of the *Dacina* (Diptera: Tephritidae) of Africa and the Middle East. *Afr Entomol Mem* 2:1-156.

White I. M., De Meyer M. , Stonehouse J. (2000). A review of the native and introduced fruit flies

(Diptera, Tephritidae) in the Indian Ocean Islands of Mauritius, Réunion, Rodrigues and Seychelles. In: Price NS, Seewooruthun I (eds) Proceedings of the Indian Ocean Commission Regional Fruit Fly Symposium, Mauritius. Indian Ocean Commission, Mauritius, 5-9 June 2000, pp 15-21.

White I. M., De Meyer M., Stonehouse J. (2001). A review of the native and introduced fruit flies (Diptera, Tephritidae) in the Indian Ocean Islands of Mauritius, Réunion, Rodrigues and Seychelles, p 15-21. In: Price NS, Seewooruthun I (eds) Proceedings of the Indian Ocean Commission Regional Fruit Fly Symposium, Mauritius. Indian Ocean Commission, Mauritius, 5-9 June 2000, pp 232.

White I. M., Elson-Harris M. M. (1992). Fruit flies of economic importance: their identification and bionomics. CAB International, Wallingford, p 601.

White I. M., Elson-Harris M. M. (1992). Fruit flies of economic significance: their identification and bionomics: CAB International.

White I. M., Goodger K. F. M. (2009). African *Dacus* (Diptera: Tephritidae); new species and data, with particular reference to the Tel Aviv University Collection. *Zootaxa* 2127:1-49.

White I., De Meyer M., Stonehouse J., Price N., Seewooruthun I. (2000). A review of native and introduced fruit flies (Diptera, Tephritidae) in the Indian Ocean islands of Mauritius, Réunion, Rodrigues and Seychelles. Proceedings of the Indian Ocean Commission, Regional Fruit Fly Symposium, Flic en Flac, Mauritius, 5th-9th June. Indian Ocean Commission.

References