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

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Abstract

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, 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* (Coquillet, 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; Castãnón-Rodriguez *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 (Elaini 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 and 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 (Figure 1A) 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 (Figure 1B). 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 [*Psidum 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 (Figure 1D).

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) (Figure 1E). 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; White and Elson-Harris 1992).

Impact

Studies reported that *Bactorcera 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; N'depo *et al.,* 2013).

Also, this fruit fly was reported in many African countries such as Angola, Benin, Cameron, 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) (Figure 1H).

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) (Figure 1G).

Impact

If uncontrolled, *D. ciliatus* causes high loss of yield but these losses are lower than those caused by *Bactrocera curcurbitae*, 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 treat 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 (Figure 1I), 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) (Figure 1F).

Detection in inspection

The monitoring of this species is based on vert lure because it is not attracted to Cue-lure(White and 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 Principé, Guinea (Conakry), Mali, Nigeria, Togo, Tanzania, Democratic Republic of Congo and Uganda (White and Elson-Harris 1992; Copeland *et al.,* 2006) (Figure 1C).

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) (Figure 1J 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) (Figure 1L).

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. corsyra* (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 Principé 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) (Figure 1O). 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 coexisting 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 coexist 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) (Figure 1N). 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.

OTHER SPECIES WITHIN GENERA CERATITIS WITH ECONOMIC IMPORTANCE

Ceratitis catoirii

C. catoirii 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.

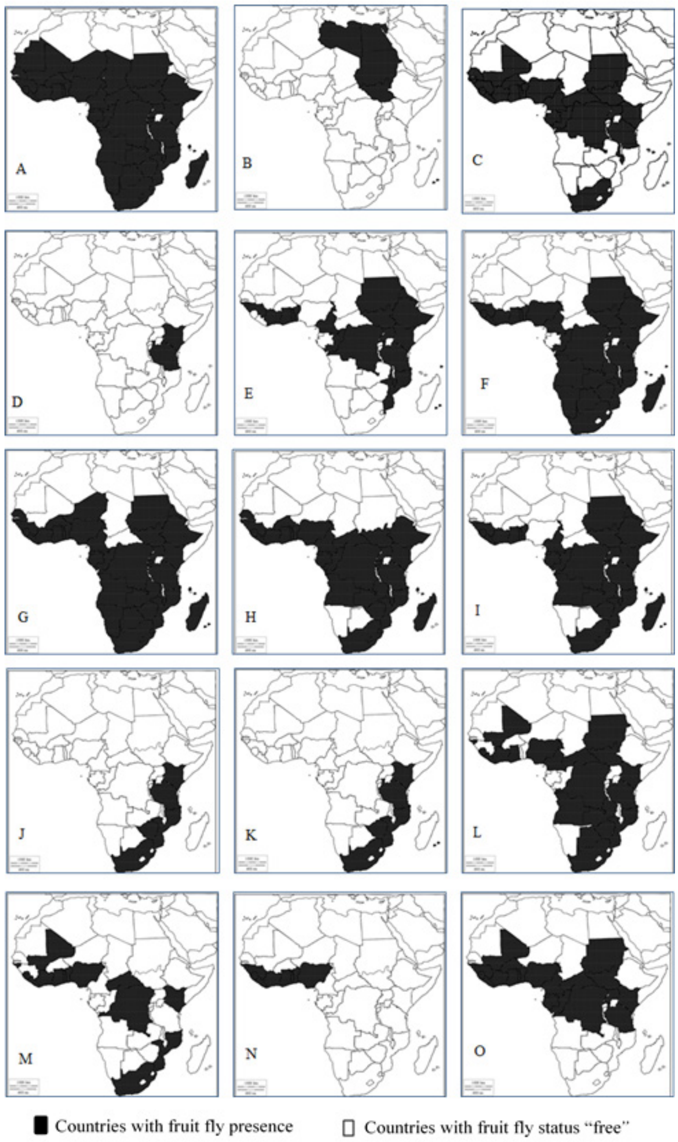

Figure 1: Maps of distribution in Africa of main fruit flies species being of biosecurity concern to Morocco. (A) B. dorsalis; (B) B. zonata; (C) C. Anonae; (D) D. latifrons ; (E) Z. cucurbitae; (F) D. vertebratus; (G) D. ciliatus; (H) D. bivittatus; (I) D. punctatifrons; (J) C. rosa; (K) C. quilicii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

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

Table 1: Host plants in Morocco of main fruit flies species with risk of invasion into Morocco from other African countries

Plant family	Host plants, common names and pest status
Cucurbitaceae	*Citrullus lanatus* (Thunb.) Matsum. & Nakai watermelon)[a,j,h,i,k,n,l], *Citrullus vulgaris* Schrad (African melon)[j], *Cucumis metuliferus* Naudin (African horned cucumber)[i], *Cucumis melo* L. (melon)[a,d,k,l,n,m], *Cucumis sativus* L. (cucumbers, gerkins)[a,d,j,h,i,l,n,m], *Cucumis melo* C. melo var. conomon (Muskmelon)[j,i,k], *Cucumis melo* var. momordica (Snap melon)[j,h], *Cucumis sativus* L. (cucumber)[h,k], *Cucumis utilissimus* Roxb (Long melon)[j], *Cucumis vulgaris* var *fi stulosus* (Squash melon)[j], *Cucurbita maxima* Duchesne (giant pumpkin)[a,g,j,h,i,n,k], *Cucurbita pepo* L. (ornamental gourd, squash)[a,j,h,i,l]
Leguminosae	*Faidherbia albida* (Delile) A.Chev.[n], *Phaseolus vulgaris* L. (French bean)[j], *Phaseolus limensis* L. (Lime bean)[j], *Phaseolus radiatus* L. (Green gram)[j]
Lauraceae	*Persea americana* Mill. (avocado) [a,b,c,d,e,f,g,j]
Malvaceae	*Abelmoschus esculentus* (L.) Moench (Okra)[j,h]
Vitaceae	*Vitis vinifera* L. (grapevine)[ag], *Vitis trifolia* Linn. (Galls grape vine)[j]
Solanaceae	*Capsicum annuum* L. cov. longum A. DC. (bell pepper)[a,e,i,k], *Capsicum chinense* Jacq. (Bonnet pepper) k, *Capsicum frutescens* L. (chilli)[a,g,j,k], *Lycium barbarum* L.(Matrimonyvine), *Lycium europaeum* L. (european boxthorn)[d], *Solanum aculeatissimum* Jacq. (Dutch eggplant)[k], *Solanum incanum* L. (grey bitter-apple)[k], *Solanum lycopersicum* L. (tomato)[a,e,g,j,h,i,m,k], *Solanum tuberosum* L. (potato)[b], *Solanum linnaeanum* Hepper and P.M. L. Jaeger (Black-spine nightshade)[k], *Solanum lycopersicum* L. var. *cerasiforme* (Alef.) Fosberg (Cherry tomato)[k], *Solanum scabrum* Mill. (Garden-huckleberry)[k]. *Solanum melongena* L. (eggplant)[j], *Solanum nigrum* L. (black nightshade)[k]
Rutaceae	*Casimiroa edulis* La Llave (white sapote)[f], *Citrus aurantiifolia* (Christm.) Swingle (lime), *Citrus aurantium* L. (sour orange)[abCgo], *Citrus grandis* (Linn.) Osbeck (Shaddock/pummel)[j], *Citrus japonica* Thunb. (round kumquat)[a], *Citrus limetta* Risso (sweet lemon), *Citrus limon* (L.) Burm. f. (lemon)[af], *Citrus × limon* (L.) Osbeck (mandarin lime), *Citrus maxima* (Burm.) Osbeck (pummelo) , *Citrus medica* L. (citron), *Citrus nobilis* Lour. (tangor)[gc], *Citrus x paradisi* Macfad. (grape fruit and Orlando)[aCdgp], *Citrus reticulata* Blanco (mandarin and Tangelo cv and Ortanique)[ab Cgj], *Citrus sinensis* (L.) Osbeck (navel orange and Tangor cv)[aCfjp], *Citrus × tangelo* J.W. Ingram & H.E. Moore (tangelo)[f], *Murraya* J.Koenig sp.C, *Murraya paniculata* (L.) Jack (orange jessamine)[g], *Clausena anisata* (Willd.) Hook.[f]. ex Benth. (horsewood)
Rosaceae	*Cydonia oblonga* Mill.[abg], *Eriobotrya japonica* (Thunb.) Lindl. (loquat) [bafg], *Fragaria chiloensis* (L.) Mill. (Strawberry)[j], *Malus communis* Poir. (apple tree)[bg], *Malus domestica* Borkh. (apple)[ag], *Malus floribunda* Siebold ex Van Houtte, *Malus pumila* Mill. (apple)[b], *Prunus africana* (Hook. f) Kalkman[Cf], *Prunus armeniaca* L. (apricot)[bg], *Prunus persica* (peach) (L.) Stokes[afgj], *Prunus* sp. L. (stone fruit)[f], *Prunus avium* (L.) L.(sweet cherry), *Prunus capuli* Cav. ex Spreng.[f], *Prunus salicina* Lindl. (Japanese plum)[g], *Pyrus communis* L. (European pear)[gj], *Pyrus malus* L. (Apple)[j] , *Pyrus pyrifolia* (Burm)[f]

Legend *: a: B. dorsalis; b: B. zonata; c: C. anonae; d : C.cosyra; e : C.catoirii; f: C. fasciventris; g: C. roza* (probably includes *C. quilicii* in published records)*; h: D. bivitattus; i: D. ciliatus; j: Zeugodacus cucurbitae; k:B. latifrons; m: D. punctatifrons; n: D. vertebratus; o: C. punctata; p: C. ditissima*

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.

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