

ORIGINAL ARTICLE

Preliminary surveys after release of the fruit fly parasitoid *Fopius arisanus* Sonan (Hymenoptera Braconidae) in mango production systems in Casamance (Senegal)

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Abstract – Introduction. Since its arrival in Senegal in 2004, *Bactrocera invadens* (Diptera Tephritidae) synonymized with *Bactrocera dorsalis* has caused much economic damage in mango crops. Effective and efficient control activities against *B. invadens* were necessary in order to continue mango production, and biological control measures were envisaged. In such conditions, the government of Senegal allowed the Asian parasitoid *Fopius arisanus* to be released in some orchards around Ziguinchor. **Materials and methods.** The dynamics of fruit fly species was studied with lure traps (methyl eugenol and terpinyl acetate with Dichlorvos). Mango fruit were sampled from the control orchard and orchards with released *F. arisanus*, to compare the differences in tephritid infestation. **Results and discussion.** The levels of *B. invadens* populations were 1.6–2.5 times higher in the control than in orchards where *F. arisanus* was released. The fruit were also 5–6 times more infested in the control orchard than in those that received *F. arisanus*. Between May and July 2012 the majority of the pupae (92%) collected from fruit samples developed into adult flies, while only 39% of the pupae transformed to adults between October and December after effective action of the parasitoids. In both orchard treatments, the level of native fruit fly populations was about the same. Wild fruit were infested mostly by *Ceratitis cosyra*, from which were reared native parasitoids such as *Fopius caudatus*, *F. silvestrii*, *F. desideratus*, *Diachasmimorpha fullawayi*, *D. carinata*, *Psytalia cosyrae*, and *P. concolor*. In contrast with *Mangifera indica*, *Citrus spp.*, *Anacardium occidentale*, *Psidium guayava*, *Saba senegalensis*, and *Landolphia heudelotii* were mainly infested by *B. invadens* which showed parasitism by *F. arisanus*. *Pteromalidae* and *Eulophidae* were also found from the pest fly pupae. Killer flies (Diptera: Muscidae) such as *Coenosia attenuata* Stein, *C. atra* Meigen and *C. tigrina* Fabricius emerged from the fruit samples. **Conclusion.** Sanitation against fruit flies in Casamance should take into account the conservation of natural enemies such as parasitoids and predators for an effective biological control of tephritids.

Keywords: Senegal / Casamance / *Mangifera indica* / mango / fruit fly / *Bactrocera invadens* / *Fopius arisanus* / biological control

Résumé – Enquêtes préliminaires après lâcher du parasitoïde de la mouche des fruits *Fopius arisanus* Sonan (Hyménoptère, Braconidae) dans des plantations de manguiers en Casamance (Sénégal). **Introduction.** Depuis son introduction au Sénégal en 2004, *Bactrocera invadens* (Diptère, Tephritidae) synonyme de *Bactrocera dorsalis*, a causé d'énormes dégâts économiques aux cultures de manguiers. Des mesures réelles et efficaces de lutte contre *B. invadens* se sont avérées indispensables pour continuer à produire des mangues, et des méthodes de lutte biologique ont été envisagées. Dans ces conditions, le gouvernement du Sénégal a autorisé l'importation du parasitoïde asiatique *Fopius arisanus* afin de le lâcher dans quelques vergers autour de Ziguinchor. **Matériel et méthodes.** La dynamique des espèces de mouche des fruits a été étudiée à partir de pièges attractifs (à base de méthyle d'eugénol et d'acétate de terpinyle associés au Dichlorvos). Les mangues ont été échantillonnées à partir d'un verger témoin et de vergers dans

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lesquels a été lâché *F. arisanus*, afin de comparer les taux d'infestation en téphritides. **Résultats et discussion.** Les populations de *B. invadens* ont été dénombrées 1,6 à 2,5 fois supérieures dans le verger témoin par rapport aux vergers où *F. arisanus* a été lâché. Les fruits en provenance du verger témoin étaient également 5 à 6 fois plus infestés que ceux des vergers traités. Entre mai et juillet 2012 la majorité des pupes collectées (92 %) à partir des fruits échantillonnés ont développé de mouches adultes, tandis qu'entre octobre et décembre seulement 39 % des pupes se sont transformées, suite à l'action des parasitoïdes. Dans les deux types de verger, le niveau des populations natives de mouches des fruits s'est montré sensiblement le même. Les fruits d'espèces sauvages ont principalement été infestés par la mouche *Ceratitis cosyra*, de laquelle ont émergé plusieurs parasitoïdes natifs tels *Fopius caudatus*, *F. silvestrii*, *F. desideratus*, *Diachasmimorpha fullawayi*, *D. carinata*, *Psytalia cosyrae*, et *P. concolor*. En revanche, les fruits de *Mangifera indica*, *Citrus spp.*, *Anacardium occidentale*, *Psidium guajava*, *Saba senegalensis*, et *Landolphia heudelotii* étaient principalement infestés par *B. invadens* dont les pupes ont également révélé les parasites *F. arisanus*, *Pteromalidae* et *Eulophidae*. Les mouches tueuses (Diptère, Muscidae) telles que *Coenosia attenuata* Stein, *C. atra* Meigen et *C. tigrina* Fabricius ont émergé des échantillons de fruits. **Conclusion.** L'assainissement de la Casamance contre les mouches des fruits devrait prendre en compte la conservation des ennemis naturels tels que parasitoïdes et prédateurs pour un contrôle biologique efficace des téphritides.

Mots clés : Sénégal / Casamance / *Mangifera indica* / mangue / mouche des fruits / *Bactrocera invadens* / *Fopius arisanus* / lutte biologique

1 Introduction

Bactrocera invadens (Drew *et al.*) synonymized with *Bactrocera dorsalis* [1] and *Ceratitis cosyra* (Walker) (Diptera: Tephritidae) are the principal pests of economic importance in mango production in the Niayes [2] and Casamance areas of Senegal [3, 4]. In Casamance farmers are not accustomed to use chemicals to control pests, and losses are up to 80% instead of 30-50% in the Niayes. The parasitoid diversity [4] showed more environmental and sanitary benefits from biological control in this area where people treated the nature respectfully. Studies undertaken from 2008 to 2012 in mango orchards of the Niayes, the Plateau of Thiès and Casamance showed that *B. invadens* severely attacked 30 mango varieties, 18 citrus species (21 cultivars) and many other host plants such as *Achras sapota* L., *Anacardium occidentale* L., *Annona muricata* L., *Annona senegalensis* Pers., *Carica papaya* L., *Capparis tomentosa* Lam., *Chrysobalanus orbicularis* Sch., *Cordyla pinnata* (Lepr.) Miln.-Red., *Diopyros mespiliformis* Hochst., *Eugenia uniflora* L., *Ziziphus mauritiana* Lam., *Psidium guajava* Radd., *Kedrostis hirtella* (Naud.) Cogn., *Phoenix dactylifera* L., *Sclerocarya birrea* (A.Rich.) Hochst., *Icacina senegalensis* A.Juss., *Landolphia dulcis* (R.Br.) Pichon., *L. heudelotii* A. DC., *L. florida* Benth., *Lannea acida* A. Rich., *Saba senegalensis* (A.DC.) Pichon., *Sarcocephalus latifolius* (Smith) Bruce, *Spondias mombin* L., *Uvaria chamea* P. Beauv. and *Ximenia americana* L. With such a broad range of hosts, *B. invadens* was rapidly more abundant than native fruit flies such as *Bactrocera cucurbitae* (Coquillett), *Dacus sp.*, *Ceratitis silvestrii* Bezzi, *C. capitata* (Wiedemann) *C. fasciventris* De Meyer *C. breinii* Guérin-Méneville, *C. punctata* (Wiedemann), *C. quinaria* (Bezzi), *Carpomyia sp.* and *Capparimyia bipustulata* (Bezzi) [2].

Community dynamics in orchards showed that *B. invadens* was more abundant than *Ceratitis cosyra*, *C. breinii*, *C. silvestrii*, *C. punctata*, *C. quinaria* and *C. fasciventris*. Within these orchards, most of the indigenous and weed plants hosted fruit flies. In those orchard fruit, tephritids were parasitized by indigenous braconids such as *Fopius caudatus* (Szépligeti),

F. silvestri (Wharton), *F. desideratus* (Bridwell), *Diachasmimorpha fullawayi* (Silvestri), *D. carinata* (Szépligeti), *Psytalia cosyrae* (Wilkinson) and *P. concolor* (Szépligeti) [4]. *F. caudatus* was the most abundant wasp, and the native parasitoids showed a greater preference for *C. cosyra* than for *B. invadens* [3]. The same behavior was found by Vayssières *et al.* [5] in Benin, where *F. caudatus* was the most important parasitoid reared from fruit infested mostly by *C. cosyra*. *B. invadens* was not substantially parasitized by these parasitoids.

In only four years, *B. invadens* spread over 8.3 million km² covering 28 countries of West, Central, and East Africa including rainforest ecosystems and savannas with 117 host plants from 43 families [6]. African ecosystems do not have an indigenous parasitoid that can effectively control *B. invadens*, but co-evolved parasitoids of this invasive pest were found in Sri Lanka where the invader fly originated. These parasitoids include Braconidae species [*Diachasmimorpha longicaudata* (Ashmead), *Psytalia incisi* (Silvestri), *Fopius arisanus* Sonnan, *Fopius sp.*]; Eulophidae (*Tetrastichus sp.*); Pteromalidae (*Spalangia sp.*) and Diapriidae (*Trichopria sp.*) (Mohamed *et al.* unpubl.; Billah *et al.* unpubl.). Quimio and Walter [7] reported that *F. arisanus* preferred mostly *Bactrocera tryoni* Froggatt and *B. jarvisi* Tryon rather than *B. cucumis* French. Moreover *F. arisanus* showed a preference for *B. invadens* over *C. capitata*, *C. cosyra*, *C. rosa* Karsch, *C. fasciventris*, and *C. anonae* Graham [8]. After the introduction of *F. arisanus* in Hawaii in 1946 it became the most abundant parasitoid controlling the invasive tephritids [9, 10]. Therefore, in 2011 the government of Senegal authorized imports of *F. arisanus* for biological control of *B. invadens*. The first releases were done in 2011, in mango orchards in Casamance where this study was carried out. This work evaluates the preliminary effect of *F. arisanus* release on major mango tephritid pests. Secondly, it evaluates the competitive effects of *F. arisanus* release on native parasitoids. Finally, it aims to identify other fly species such as Muscidae *Coenosia* that develop in fruit besides tephritid flies.

2 Materials and methods

Orchards in Casamance differ from the orchards in the Niayes. There are few export-oriented plantations; rather most of the orchards are small scale and dedicated to the local market. These traditional orchards are planted with mango, cashew and citrus and receive little or no maintenance. Traditional orchards are often bounded by hedges of *Jatropha curcas* L., *Euphorbia balsamifera* Ait., *Dichrostachys cinerea* (L.) Wight & Arn., *Eucalyptus* sp., and *Mezoseuromia benthamianum* Baill. Infrequent weed clearance encourages wild fruit species such as *A. senegalensis*, *I. senegalensis*, *Sorindeia juglandifolia* (A. Rich.) Planch. ex Oliv., *L. dulcis*, *L. florida*, *L. heudelotii*, *L. acida*, *S. senegalensis*, *S. latifolius*, *S. mombin*, *U. chamea*, and *X. americana*. In these traditional orchards the density of some wild fruit species is often higher than the cultivated crops (mango, cashew or citrus) [2]. Our study focused on these traditional plots.

In total 5,000 wasps of *F. arisanus* reared from IITA/Benin were released in each of three orchards in June 2012. A fourth orchard located 30 km away from the nearest release orchard, did not receive any release of this parasitoid (control). As with most of the orchards in Casamance, the chosen farms were 1 to 2 ha in size planted with mango, cashew and citrus, and were surrounded by forest. After a six-month baseline survey in Casamance in April–September 2010 [4] investigations were pursued from September 2011 to September 2012 to evaluate the effect of *Fopius arisanus* releases. A weekly survey of the fruit fly populations was done in the four orchards using two kinds of traps at each location: i) semiochemical lure traps [Tephritraps with methyl eugenol + DDVP (2, 2 Dichlorovinyl dimethyl-phosphate) and terpinyl acetate + DDVP] [11] and, ii) food lure traps [Tephritraps with water and a food attractant such as *Torula*] were used in each orchard. A total of 2,509 fruits (148.4 kg) were collected from trees and on the ground under these trees inside and around the four orchards 1,254 fruits before and 1,255 fruits after the release dates.

Sampling was performed over a full year to cover the fruiting seasons of the major host plants in order to collect information on the whole range of fruit flies and parasitoids from each fruit species. Fruit samples were returned to the laboratory of ISRA/Djibelor, Senegal. In the sampling areas available mature fruit of cultivated (mango, citrus, cashew...) and wild species at prematurity and mature (ripe) stages were randomly sampled on a weekly basis. Plant species were determined using the flora guide of West African dry zones [12, 13] and that of Senegal [14]. Fruit fly species were determined using insect identification keys [15, 17] and results were confirmed by Vayssières et al. [5]. Parasitoid identifications were done by Wharton [4] at Texas A&M University (USA).

Data on fruit fly infestation rate, parasitism rate, parasitoid species and abundance were recorded. Percentage parasitism was calculated as $\frac{a}{a+b} \times 100$, where a = number of emerged parasitoids, and b = number of emerged adult flies in each sample [4]. Analysis of variance was performed using the general linear model procedure and mean separations were done using the Fisher test, normality and KHI 2 tests were used (SAS 2003) [18]. A principal component analysis was performed for interactions among fruit flies and parasitoids. A Shannon

index of biodiversity was estimated for each host plant using $D_{Sp} = \sum_{i=1}^n -p_i \ln(p_i)$, with: D_{Sp} = biodiversity index; each orchard or host plant i was associated $P_i = n_i/N$ with n_i = the number of insects (Tephritidae, Muscidae and Braconidae) emerged from the orchard or host plant i , and N = the total individuals for this insect.

3 Results

3.1 Fruit fly dynamics in the orchards

Fruit flies were trapped from January to August in the four orchards. In the traps *B. invadens* was always the most abundant fruit fly species (figure 1) compared to native species such as *C. cosyra*, *C. silvestrii*, *C. bremii*, *C. punctata*, *C. quinaria* and *C. fasciventris*. The same phenomenon was found in the rainy season (June–October) with the Tephritraps using water and *Torula* as food attractant: *B. invadens* (83%) was more abundant than *C. cosyra* (12%), *C. capitata* (2.8%), *C. silvestrii* (1.1%), *C. fasciventris* (0.1%). At peak periods *B. invadens* was 1.6–2.5 times more abundant in the control orchard than in the farms where *F. arisanus* was released. The *B. invadens* level decreased one week after releases, while its populations continued to increase in the control orchard. The abundance of native flies remained roughly the same in all orchards. It was confirmed by the non-attendance of significant difference between the diversity indexes in the orchard $P = 0.067$ (figure 2). Among these native flies, *C. cosyra* was the most abundant. The size of *C. silvestrii* population was more important in the dry season (November–May) than the rainy season, in contrast with *C. bremii* and *C. punctata*.

The diversity of fruit flies trapped was analyzed in the four orchards. The diversity index of fruit fly species has been computed for each orchard (figure 2). This index was found to vary from one orchard to another with no relation to parasitoid release. Such variability was mostly due to the composition in host plants in the orchard. Orchard 2 had the smallest peak of fruit fly population but had the greatest diversity among the trapped fruit flies. Orchard 1 and the control had diversity index values above the mean (1.9) of all orchards. Among the three treated orchards two had a biodiversity index lower than the control. Although the control orchard had an index value of biodiversity just above the average its infestation by *B. invadens* was the highest. Thus it seems that the population size of *B. invadens* was not linked to the biodiversity in the orchard. Other factors should play a role such as the diversity of cultivated and wild host plants in the orchard and the frequency of cultural maintenance

3.2 Fruit infestation in release orchards

From the 2,509 sampled fruits of the study, about half of them (1,259 fruits) were infested by fruit flies, and 68% of these infested fruits were collected before release. A number of 23,663 pupae were reared from these infested fruits, of which 61% were Tephritidae, 10% were Braconid parasitoids, and 1% Eulophidae or Pteromalidae. Flies such as Muscidae

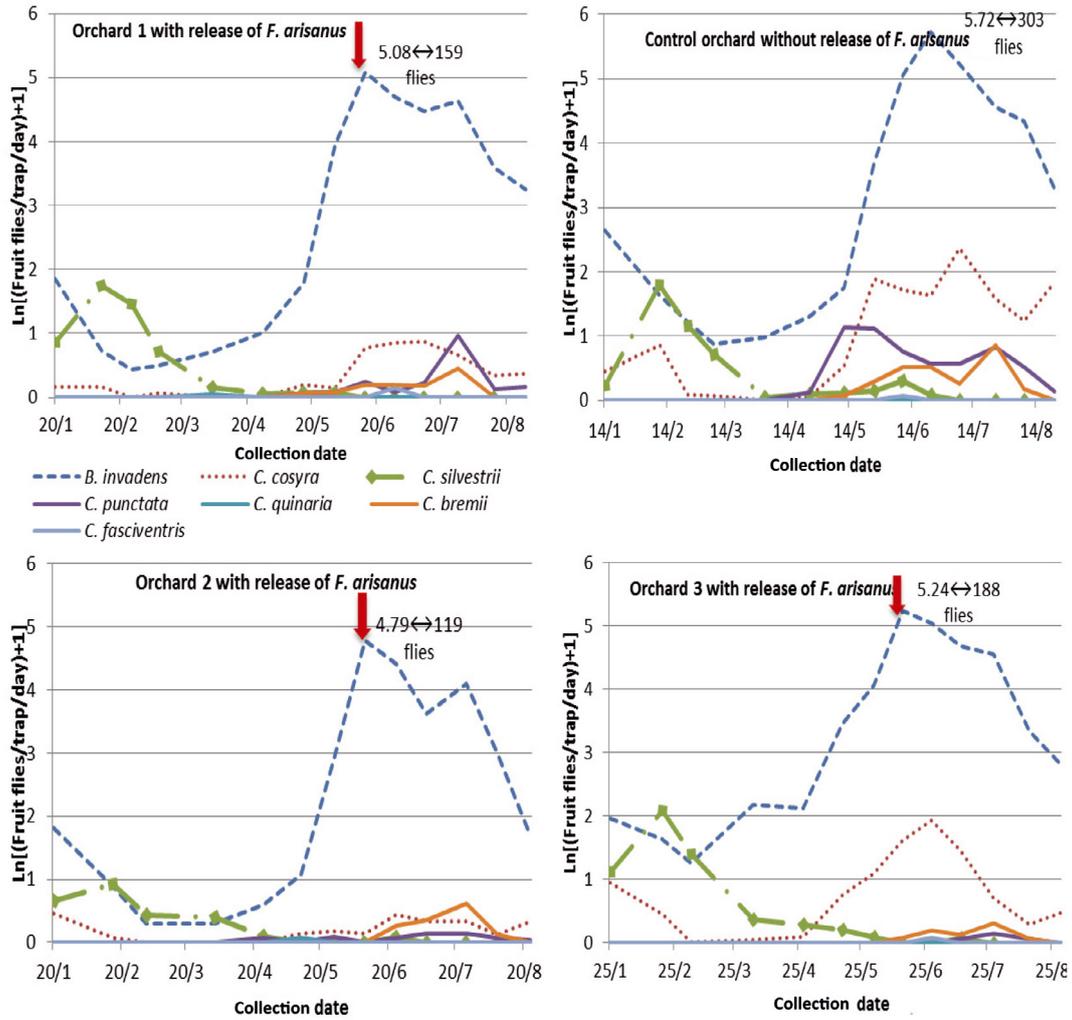


Figure 1. Fluctuation of fruit fly populations in orchards before and after *F. arisanus* release in 2012 (Release date is shown by the vertical arrow).

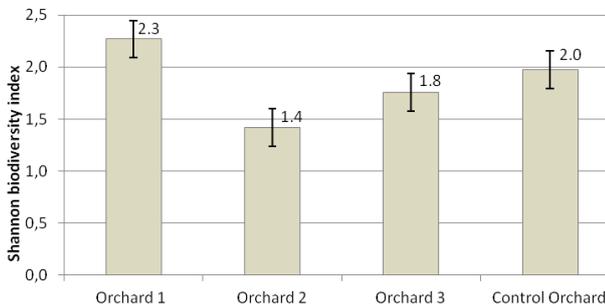


Figure 2. Biodiversity in the studied orchards (Fisher’s test: $P = 0.067$, $n = 14$ collecting dates per orchard).

were also reared from the fruit samples. The fruits regularly sampled allowed us to study the dynamics of the tephritids and braconids per kg (figure 3).

From the fruit sampling two periods could be distinguished with peak infestations (figure 3). From May to August all fruit were infested with 92% of the pupa yielding fruit flies, while

from September to January only 39% of the pupa yielded fruit flies. After a high record of parasitoid emergence, most of the pupae (61%) did not yield flies. The fruit fly emergence is low from September to February and from February to May fruit are rare in the orchards and surrounding forests.

With the first fruit available in April, infestation by fruit flies started to increase. From June to July more than 92% of pupae yielded fruit flies. At the same time the braconid populations increased and became more important between July and September (figure 3). When they became adult, these parasitoids were effective biocontrol agents that developed within fruit fly eggs and larvae, thus reducing considerably the pest emergence between November and December. If one would consider a whole year, the wasp fluctuation should follow a normal distribution with a peak between July and September (for $\alpha = 0.05$; p -value = 0.600; $\text{JB}_{(\text{Observed Value})} = 1.021$; $\text{JB}_{(\text{Critical Value})} = 5.991$; $\text{df} = 2$; and the risk to reject H_0 whereas it is true up to 60.03%). Fruit were significantly more infested in the control orchard than in orchards where *F. arisanus* was released ($P = 0.006$, $r = 0.76$) (figure 4).

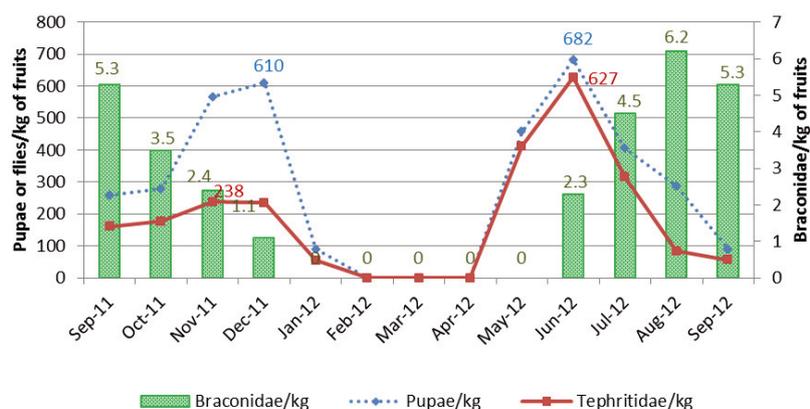


Figure 3. Fluctuation of pupae, reared fruit flies and Braconidae per mass of fruit infested in 2012.

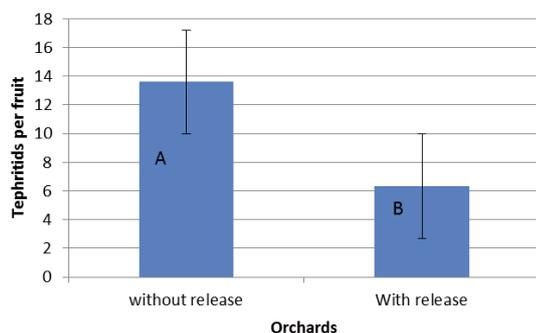


Figure 4. Pest flies emerging per fruit from orchards with and without *F. arisanus* release (data from 2012, LSD-value = 2.26, Fischer's test: $P = 0.006$, $n = 1,259$ fruits).

3.3 Fruit flies and parasitoids according to host plants

Whenever the orchard received *F. arisanus* release or not, fruit were mostly infested by the same pests: *B. invadens*, *C. cosyra*, *C. silvestrii* and *C. punctata*. From these fruit, the emerging procession of parasitoids was enriched by *F. arisanus*, which started to reproduce in the orchards in addition to the indigenous species: *F. caudatus*, *F. silvestrii*, *F. desideratus*, *D. fullawayi*, *D. carinata*, *P. cosyrae* and *P. concolor*. Other parasitoids belonging to the Pteromalidae and Eulophidae were reared from fruit fly pupae in these fruit samples.

A principal components analysis of these data was carried out, taking into account the *F. arisanus* release effects (figure 5). On the F1-axis, wild plants had fruit infested mainly by flies like *C. cosyra*, *C. silvestrii* and *C. punctata*. These wild plants included *A. senegalensis*, *S. latifolius*, *I. senegalensis* and *L. dulcis*. In their fruit, the native tephritids were parasitized mostly by native braconids such as *F. caudatus*, *F. silvestrii*, *F. desideratus*, *D. fullawayi*, *D. carinata*, *P. cosyrae*, *P. concolor* and a few wasps from Pteromalidae and Eulophidae. All these wasps were dominated by *F. caudatus* and host parasitoids seemed to control the pests significantly.

On the other hand, the F2-axis showed cultivated and wild plants of which most have economic importance (figure 5). This group of plants including *M. indica*, *Citrus sp.*, *A. occidentale*, *P. guayava*, *S. senegalensis* and

L. heudelotii, were mainly infested by *B. invadens* that was mainly parasitized by *F. arisanus*. Wasps of Pteromalidae and Eulophidae were reared from pupae of *B. invadens* and *Ceratitis* species. The most infested host plants also produced fruit for a long period in the field: 9 months for *S. latifolius*, 7 months for *M. indica* and *A. occidentale*, 4 months for *L. dulcis* and *A. senegalensis*, and 3 months for *I. senegalensis*.

3.4 Killer flies (Muscidae) found in fruit samples

In addition to the tephritid pests and their parasitoids in the Braconidae, Eulophidae and Pteromalidae some adults of killer flies were found from the pupae received from fruit samples. These killer flies or hunter flies (genus *Coenosia* Meigen (Muscidae: Coenosiniinae)) included *Coenosia attenuata* Stein, *C. atra* Meigen, and *C. tigrina* Fabricius. Based on the host fruit from which fruit fly and killer fly pupae were collected a matrix of correlation was established (table I). On the one hand fruit flies like *C. cosyra* and *C. silvestrii* were highly correlated each other ($r = 0.925$). On the other hand they were both correlated to the killer fly *C. tigrina* ($r = 0.786$ and 0.731 resp.). The two other killer flies *C. attenuata* ($r = 0.794$) and *C. atra* ($r = 0.570$) emerged mostly from fruit infested by *B. invadens*.

Muscidae and Tephritidae were also assessed through the host plants from which they emerged (figure 6). This principal component analysis was based on six host plants infested by flies such as *B. invadens*, *C. cosyra*, *C. silvestrii* and *C. punctata*. *Sarcocephalus latifolius* was mostly infested by the pest *C. cosyra* and *C. silvestrii* and by the predator *C. tigrina*. *Psidium guayava* was mostly infested by the pest *B. invadens* and the predator *C. attenuata* and *C. atra*. Next to the presence of hunter flies, we can note an important diversity of insects in the sampled fruits many of them infested by tephritid and killer flies. Considering all these insects, the biodiversity index per host plant was fluctuating (table II) indicating the main diversity of pest, parasitoids and killer flies was issued from the fruit. Plants mostly infested by fruit flies such as *A. senegalensis*, *S. latifolius*, *I. senegalensis*, *M. indica*, *L. dulcis* and *P. guayava* had more abundant parasitoids and killer flies. Consequently plants most infested by pest flies also contained high number of parasitoids and predators such as hunter flies for natural biological control. For example from an overall of 755 fruits

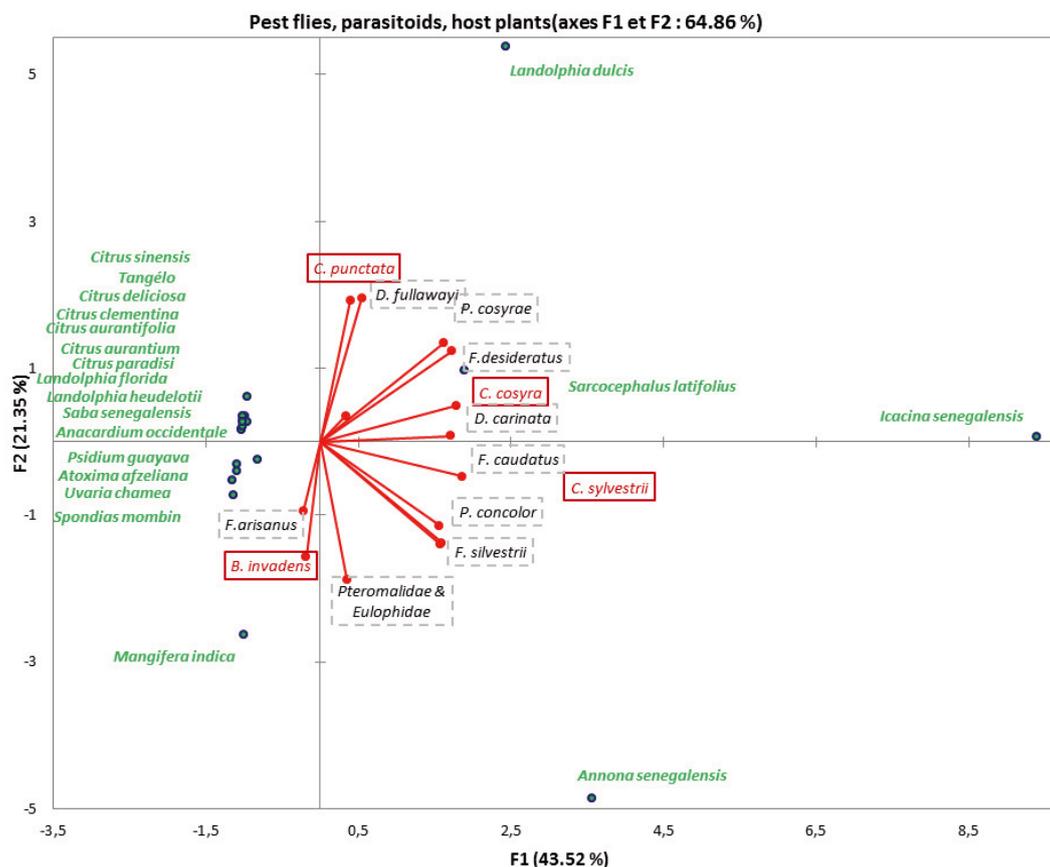


Figure 5. Distribution of the pests (in red) and their parasitoids (in black) through the host plants (in green) (data from the 2012 survey). Axis F2 mostly explains the contributions of two pest flies *B. invadens* and *C. punctata* and 2 braconids *F. arisanus* and *D. fullawayi* while the other braconids and the 2 pest flies *C. cosyra* and *C. silvestrii* contributed to axis F1.

Table I. Matrix of correlation (Pearson (n)) between fruit flies and killer fly. Figures in bold are significant ($P < 0.05$).

	<i>Bactrocera invadens</i>	<i>Ceratitidis cosyra</i>	<i>Ceratitidis silvestrii</i>	<i>Ceratitidis punctata</i>	<i>Coenosia attenuata</i>	<i>Coenosia tigrina</i>	<i>Coenosia atra</i>
<i>Bactrocera invadens</i>	1						
<i>Ceratitidis cosyra</i>	0.039	1					
<i>Ceratitidis silvestrii</i>	-0.172	0.925	1				
<i>Ceratitidis punctata</i>	-0.329	-0.333	-0.200	1			
<i>Coenosia attenuata</i>	0.794	0.305	-0.001	-0.252	1		
<i>Coenosia tigrina</i>	-0.369	0.786	0.731	-0.306	-0.132	1	
<i>Coenosia atra</i>	0.570	0.025	0.014	-0.746	0.307	-0.293	1

sampled on *S. latifolius*, 18,304 pupae were collected. From these pupae 54% were fruit flies *B. invadens* (1%), *C. cosyra* (98%), *C. punctata* (1%) and 11% were parasitoids 90% of which were *F. caudatus*.

4 Discussion

In our results fruit flies were more abundant in the orchards without release of *F. arisanus* than orchards where this wasp was released. This dynamic was mainly due to the abundant flies yielded by infested fruit in orchards without release. Fruit samples from orchards that received the released wasps were less infested and yielded less abundant flies. The important

number of fruit species and their long period of production (from 3 to 9 months) contribute to increase the tephritid populations in the orchards. In addition farmers aren't accustomed to use chemical to control pest. Therefore the uses of parasitoids that fight naturally against the invader fly are more beneficial. These preliminary results of these inoculative releases seem promising. It encouraged the government to reinforce this activity to achieve a level such as exhibited by Harris *et al.* [19] who got a decrease of pest fly populations 23 times less after release than before. This decrease is clear with the populations of *B. invadens*, which is the species preferred by *F. arisanus* according to Mohamed *et al.* [8].

The most abundant native parasitoid (*F. caudatus*) exclusively parasitizes *Ceratitidis* MacLeay [20, 24]. We found

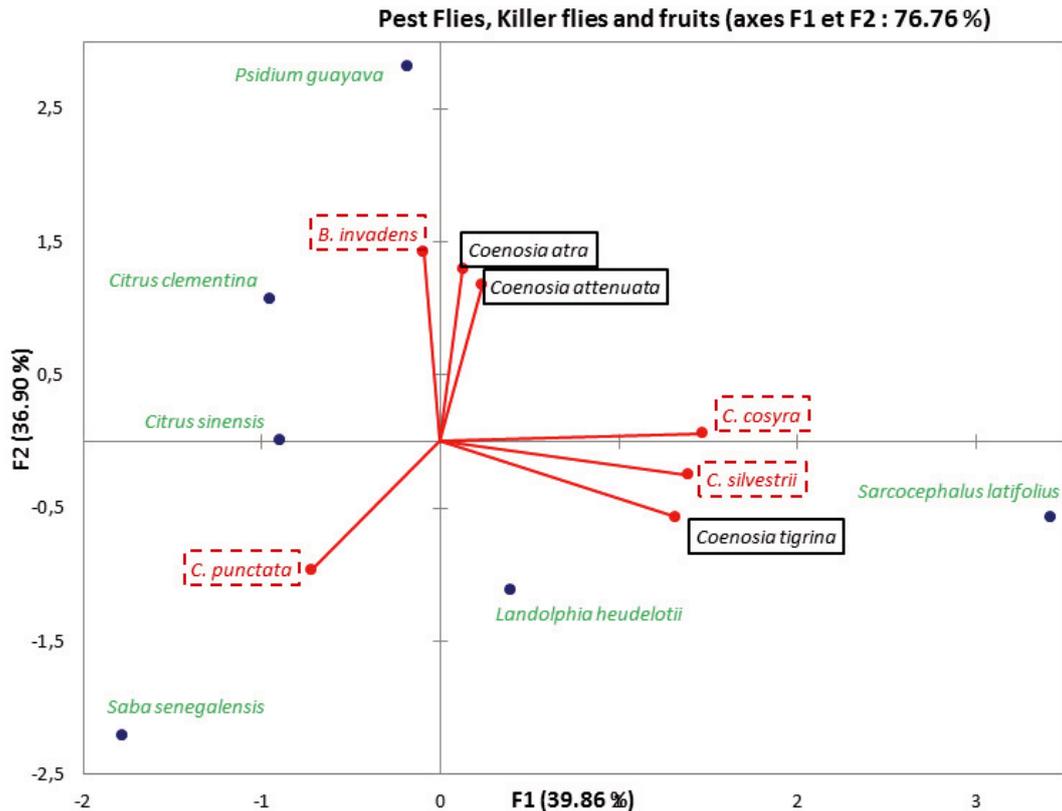


Figure 6. Distribution of pest flies (red dotted box) and killer flies (in black plain box) through their host plants (green spot). *B. invadens* and Killer flies such as *C. atra* and *C. attenuata* contributed mostly to hold axis F2 while pest flies like *C. cosyra* and *C. silvestrii* and the killer *C. tigrina* contributed to axis F1.

Table II. Diversity of insects (pest flies, parasitoids and killer flies) found in a range of fruit trees present in or around the studied orchards.

Fruit tree species	Shanon diversity index $\sum -pi \ln(pi)$	Standard Error
<i>Anacardium occidentale</i>	0.50	0.02
<i>Annona senegalensis</i>	3.30	0.03
<i>Citrus aurantifolia</i>	0.20	0.01
<i>Citrus clementina</i>	0.60	0.03
<i>Citrus sinensis</i>	0.40	0.02
<i>Ficus sur</i>	0.30	0.02
<i>Icacina senegalensis</i>	2.20	0.02
<i>Landolphia dulcis</i>	1.60	0.03
<i>Landolphia florida</i>	0.50	0.02
<i>Landolphia heudelotii</i>	0.90	0.02
<i>Mangifera indica</i>	2.10	0.04
<i>Psidium guayava</i>	1.30	0.03
<i>Saba senegalensis</i>	0.60	0.02
<i>Sarcocephalus latifolius</i>	3.20	0.03
<i>Spondias mombin</i>	0.50	0.02
<i>Uvaria chamea</i>	0.10	0.03
<i>Ximenia americana</i>	0.20	0.02

this wasp mostly in fruit infested by *C. cosyra*. *F. caudatus*, *F. arisanus* and *F. ceratitivorus* that are egg-pupal parasitoids, attack hosts in the earliest stages [20–23]. They are

more competitive than those that parasitize flies in later stages. All the 6 other wasps were shown to be larval-pupal parasitoids. *Psytalia cosyrae* is a larval-pupal parasitoid [25, 26] that attacks *C. cosyra* in mango and wild fruit [27, 28] as well as several species belonging to *Bactrocera dorsalis* complex. *Psytalia concolor* parasitizes the second and last larval stages of *Ceratitidis capitata* [29,30]. Its hosts include other fruit flies such as *Ceratitidis*, *Capparimya*, *Carpomya*, and *Dacus* ones [31]. *F. silvestrii* infests *C. capitata*, and *Dacus bivittatus* [24, 32] while *F. desideratus* infests flies from the genera of *Ceratitidis* and *Dacus*. *D. carinata* infests species of *Ceratitidis* and *Bactrocera* Macquart while *D. fullawayi* parasitizes several species of *Ceratitidis* such as *C. capitata* [20]. All these native parasitoids contribute to maintain native fruit flies at low levels compared to the invader fly. The fruit fly biological control was reinforced by the action of *F. arisanus* in the orchards where it was released. In our results, *F. caudatus* preferred species of *Ceratitidis* such as *C. cosyra*, *C. sylvestrii*, *C. punctata* while *F. arisanus* preferred mostly *B. invadens*. The preference for *B. invadens* instead of *Ceratitidis* species like *C. capitata*, *C. cosyra*, *C. rosa* Karsch, *C. fasciventris*, and *C. anonae* Graham was reported by Mohamed et al. [8]. It is based on the hypothesis that after the release in the orchard, the females quickly explore and parasitize fruit fly eggs in mango [33]. Beside mango, *F. arisanus* tracked mostly *B. invadens* in its wide host range including *Citrus spp.*, *Psidium guayava*, *Spondias mombin*, *Anacardium occidentale* and

Saba senegalensis. These results confirmed those obtained by Eitam and Vargas [34] who mentioned a parasitism rate from 41 to 72% of *Bactrocera dorsalis* by *F. arisanus* in the fruit of *Psidium cattleianum* Sabine, *P. guajava*, and *Terminalia catappa* L. In Kenya, Ekesi [35] obtained a parasitism rate in mango of up to 40% of *B. invadens* in the field. *F. arisanus* could also parasitize *C. capitata*, *C. cosyra* and *C. anonae* [8]. This wasp was reported as polyphagous parasitoid infesting 40 host flies [36–43]. Finally *F. arisanus* prefers *B. invadens* while *F. caudatus* prefers *C. cosyra* and *C. silvestrii* and this provides more confidence for the biological control of our major mango pest flies *B. invadens* and *C. cosyra* [2, 4]. The control included the action of the gregarious parasitoids like Pteromalidae and Eulophidae as shown before by Vayssières *et al.* [4] in the same area.

The correlations established between these killer flies (*Coenosia attenuata*, *C. tigrina* and *C. atra*) and the pest flies (*B. invadens*, *C. cosyra* and *C. punctata*) seemed to promise some potential of biological control. Additional experiments need to be done for more information.

5 Conclusion

Fruit heavily infested by fruit flies received naturally more parasitoids and predators. Consequently sanitation activities in orchards must take into account all biological agents including parasitoids and generalist predators. Among generalist predators killer flies and weaver ants have to be taken into account since they are also useful biological control agents [44]. As the first major mango pest (*C. cosyra*) is parasitized by an egg-attacking wasp (*F. caudatus*) combined with others during the larval stages, the releases have to combine the egg-pupal parasitoid (*F. arisanus*) with other larval-pupal parasitoids such as *D. longicaudata* and *D. incisi* to control *B. invadens* at its different stages.

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