Native parasitoids associated with fruit flies (Diptera: Tephritidae) in cultivated and wild fruit crops in Casamance, Senegal

J-F. Vayssières[1*], A. Adandonon[2], O. N'Diaye[3], A. Sinzogan[4], C. Kooymann[5], K. Badji[6], J-Y. Rey[7] & R.A. Wharton[8]

[1]*CIRAD, UPR HortSys; TA-PS4, Bd de la Lironde, 34398-Montpellier, France, and IITA, Biocontrol Unit for Africa, 08 BP 0932, Cotonou, Benin*

[2]*ENSTA-Kétou, Université d'Abomey-Calavi, Rép. Bénin, and IITA, Biocontrol Unit for Africa, 08 BP 0932, Cotonou, Benin*

[3]*Doctorant en Biodiversité et Environnement: écologie et gestion des écosystèmes, ED-SEV/UCAD, Dakar, Senegal*

[4]*FSA, Université d'Abomey-Calavi, Rép. Bénin, and IITA, Biocontrol Unit for Africa, 08 BP 0932, Cotonou, Benin*

[5]*Responsable R&D Eléphant Vert Rabat, Morocco*

[6]*Laboratoire de Zoologie Agricole, Direction de la Protection des Végétaux (DPV), Km 15 Rte de Rufisque BP 20054 Thiaroye, Dakar, Senegal*

[7]*CIRAD, UPR HortSys; TA-PS4, Bd de la Lironde, 34398-Montpellier, France, and ISRA/ CIRAD, ISRA/CDH, BP 484, Thiès, Senegal*

[8]*Department of Entomology, Biological Control Facility, Texas A&M University, College Station, Texas, 77843-2475, U.S.A.*

Fruit flies are pests of economic importance in West Africa due to their quarantine status and losses recorded in fruits and vegetables. Before the introduction of exotic species of parasitoids against any exotic fruit fly species, it is fundamental to first determine the presence and monitor the native parasitoid species. This work was carried out in Casamance (Senegal), during the rainy season of 2010, with sampling of 5191 fruits from 22 plant species. Seven species of parasitoids (all Braconidae) were recorded and reared from six fruit species. The parasitoids included *Fopius caudatus* (Szépligeti), *F. silvestrii* (Wharton), *F. desideratus* (Bridwell), *Diachasmimorpha fullawayi* (Silvestri), *D. carinata* (Szépligeti), *Psyttalia cosyrae* (Wilkinson) and *P. concolor* (Szépligeti). The most abundant species was *F. caudatus* (63.97 %). The overall mean parasitism rate observed in all samples was 2.4 ± 1.3 %. *Ceratitis cosyra* (Walker) (77 %) was the host fly most commonly reared from fruits yielding parasitoids including *F. caudatus*. *Annona senegalensis* Pers. was the fruit species most frequently infested by fruit flies and *Saba comorensis* (Boj. ex DC) Pichon fruits had the highest parasitism rates. In the current work, there were no parasitoids reared from the recently introduced pest, *Bactrocera invadens* Drew, Tsuruta and White. This is the first report of all these reared parasitoids, except *D. fullawayi*, in Senegal.

Key words: biological control, *Bactrocera invadens, Ceratitis* spp., Tephritidae, Braconidae.

INTRODUCTION

Fruit flies (Diptera: Tephritidae) are of major economic importance in horticulture in tropical regions (Mwatawala *et al.* 2006; Billah *et al.* 2008; Vayssières *et al.* 2008). In fact, many species in this family attack and severely damage important fruit crops such as mango (*Mangifera indica* L.), *Citrus* species and cashew (*Anacardium occidentale* L.). Control of fruit flies has been the focus of many fruit fly research programmes, some of them dealing with biological control through the use of parasitic Hymenoptera (Silvestri 1913; Wharton 1989; Sivinski *et al.* 2000; Bokonon-Ganta & Messing 2008). Numerous studies have demonstrated the possible use of parasitoids for fruit fly suppression (Sivinski *et al.* 2000; Vargas *et al.* 2007). Thus, parasitoids from Africa, including several species of *Psyttalia* and *Fopius*, have attracted much interest for use as biological control agents against fruit flies (Silvestri 1913; Wharton *et al.* 2000; Billah *et al.* 2008; Rousse & Quilici 2009). Moreover, the African continent has been the focus of recent collections and surveys of parasitoids for export to other regions to control fruit fly pests (Wharton *et al.* 2000; Rugman-Jones *et al.* 2009). One such example of a parasitoid survey is the recent research conducted in Benin on preliminary inventory of parasitoids associated with fruit flies in mangoes, guavas (*Psidium guajava* L.),

*To whom correspondence should be addressed.
E-mail: j.vayssieres@cgiar.org

cashew, pepper (*Capsicum annuum* L.) and wild fruit crops (Vayssières *et al.* 2011a).

Mango is a particularly important tropical fruit for sub-Saharan national and regional economies, as well as for export (Vayssières *et al.* 2008). Unfortunately, the crop is attacked by both native species such as *C. cosyra* and by a new invasive species, *B. invadens*, which cause great economic losses in both East and West Africa (Vayssières *et al.* 2011a). In Senegal, for instance, damage caused by fruit flies, especially *B. invadens*, ranged from 30 to 50 % in mango orchards in the Niayes region, and up to 60 % in the Ziguinchor region of Casamance (Ternoy *et al.* 2006). In the Niayes region, 18 fruit fly species were identified including 10 *Ceratitis*, six *Dacus* and two *Bactrocera* species (Vayssières *et al.* 2011b). On-going country-wide fruit fly monitoring from 2007 in mango and citrus orchards by Vayssières *et al.* (unpubl.) in Senegal confirms high tephritid populations and the threat they present to fruit plantations in the country. These fruit fly populations are also alternatively hosted by wild fruits that are present during most of the year in or around commercial fruit orchards. Thus, these populations constitute a residual but permanent reservoir for the fruit fly infestations of these orchards (Vayssières *et al.* 2011a).

To our knowledge, little information is available about the natural enemies attacking tephritid pests of fruit crops in Senegal, especially in the Casamance region. The known record of the fruit fly parasitoid fauna in Senegal before this study refers to *Diachasmimorpha fullawayi* (Silvestri 1912), *Psyttalia dexter* (Silvestri 1913) and *Coptera silvestrii* (Yoder & Wharton 2002; Silvestri 1914). The objective of the current work was to identify native parasitoid species in the Casamance region in order to provide baseline data on pest control potential in future biological control programmes.

MATERIAL AND METHODS

A six-month survey was carried out in Casamance, around Ziguinchor (within a 40 km radius), from April to September 2010 during the fruiting season for major fruit crops to determine the fruit fly species and parasitoids from the selected fruit crop species. The Casamance region belongs to the Sudano-Guinean area with a rainy season of about six months and a dry savanna. During the survey, all available mature fruits of any species in the area, cultivated and wild, at prematurity and maturity stages were haphazardly sampled each week according to the availability from trees in orchards of mango, citrus, cashew and also from wild fruit trees in the surrounding forests. The number of sampled fruits and corresponding fruit trees are given in Table 1. Fruit samples were brought to the laboratory where incubation and collection of pupae and adults were done as described by Vayssières *et al.* (2011a). Fruit crop species and fruit fly identifications were performed by O. N'Diaye (ISRA, Senegal) and confirmed by J-F. Vayssières (CIRAD-IITA, Benin) using the flora guide of West African dry zones (Irvine 1961; Arbonnier 2004) and that of Senegal (Berhaut, 1971–1979) and insect identifications keys (De Meyer 1998a,b; De Meyer & Freidberg 2005).

Parasitoid identifications were done by R. Wharton in the laboratories of the Texas A&M University, with voucher specimens deposited in the Insect Collections in Texas A&M University (Reference nos RVA 2497–2526).

Data analysis

Data on fruit fly infestation rate, parasitism rate, parasitoid species and abundance were recorded. Percentage parasitism was calculated as $a/(a + b) \times 100$, where a = number of emerged parasitoids, and b = number of emerged adult flies in each sample.

Infestation rate was calculated as the number of pupae/kg fruit. Log10 $(x+1)$ transformation was used on percentage data to stabilize the variance and normalize the data. Analysis of variance was performed using the general linear model procedure and mean separations were done using the Student-Newman-Keuls test (SAS 2003). A principal component analysis was performed on the interactions between hosts, fly species and parasitoid species.

RESULTS AND DISCUSSION

The number of collected fruits per crop species during the survey is shown in Table 1. A total of 5191 fruits were collected from 22 fruit species for incubation in the laboratory. Only six fruit species, namely *Anacardium occidentale L., Annona senegalensis* Pers., *Icacina senegalensis* (A.) Juss., *Landolphia dulcis* (Sabine) Pic., *Saba comorensis* (Boj. ex DC) Pichon and *Sarcocephalus latifolius* (Smith)

Table 1. Infestation indices, parasitism levels and period of occurrence of fruit flies and parasitoids reared from sampled fruits in Casamance in 2010.

				Period of occurrence of fruit flies***				Period of occurrence of parasitoids***					
Fruit plants (family)*	No. fruit	No. puparia/ kg fruit**	% Parasitism	*B. invadens*	*C. cosyra*	*C. silvestr.*	*C. punct.*	*F. caudat.*	*F. silvestr.*	*F. des.*	*Diach*. spp.	*P. cosyrae*	*P. concolor*
Anacardium occidentale L. (Ana.)	310	7.6 ± 2.3 a	4.32	Jn, Jl	Jl	–	–	–	–	Jl	–	–	–
Annona senegalensis Pers. (Ann.)	515	752.2 ±12.6 d	0.64	Jl, Au	Jn–Au	My, Jn	–	Jn, Jl	–	Jn	–	–	–
Cissus araloïdes Welw. ex Bak. (Vit.)	23	0 a	0	–	–	–	–	–	–	–	–	–	–
Citrus aurantium L. (Rut.)	3	0 a	0	–	–	–	–	–	–	–	–	–	–
Clausena anisata (W.) H. ex B. (Rut.)	40	0 a	0	–	–	–	–	–	–	–	–	–	–
Cnestis ferruginea Vahl ex DC (Con.)	163	0 a	0	–	–	–	–	–	–	–	–	–	–
Ficus spp. (Mor.)	30	0 a	0	–	–	–	–	–	–	–	–	–	–
Ficus sur Forsk. (Mor.)	16	222.2 ± 10.5 b	0	Jl	–	–	–	–	–	–	–	–	–
Icacina senegalensis (A) Juss. (Ica.)	642	297.2 ± 33.4 c	7.18	–	Jn–Au	Jn–Au	–	Jn–Au	Au	Au	Au	–	Au
Landolphia dulcis (Sabine) Pic. (Apo.)	357	199.0 ± 6.2 b	1.94	–	Au	–	Jn–sp	Jl	–	–	Jl, Au	Jn, Jl	–
Landolphia heudelotii A. DC. (Apo.)	423	5.2 ± 1.0 a	0	Jl	–	–	–	–	–	–	–	–	–
Lannea spp. (Ana.)	305	0.0 a	0	–	–	–	–	–	–	–	–	–	–
Mangifera indica L. (Ana.)	81	244.5 ± 8.3 b	0	Jn–Au	My	–	–	–	–	–	–	–	–
Saba comorensis Boj (ex DC) P. (Apo.)	302	0.3 ± 0.2 a	25.0	–	–	–	Au	–	–	Jl	–	–	–
Saba senegalensis (A. DC.) P. (Apo.)	19	0 a	0	–	–	–	–	–	–	–	–	–	–
Sarcocephalus latifolius (Sm.) B (Rub.)	411	232.5 ± 27.8 b	8.21	Au	Jn–Au	–	Jl	Jl, Au	Jl, Au	Au	Au	Jl, Au	–
Sorindea juglandifolia L. (Ana.)	1243	0 a	0	–	–	–	–	–	–	–	–	–	–
Spondias mombin L. (Ana.)	53	0.56 ± 0.01 a	0	Au	–	–	–	–	–	–	–	–	–
Vitex madiensis Oliv. (Ver.)	173	0 a	0	–	–	–	–	–	–	–	–	–	–
Ximenia americana L. (Ola.)	22	4.7 ± 0.1 a	0	Jn	–	–	–	–	–	–	–	–	–

**Ficus* spp. = *Ficus exasperata* and *Ficus gnaphalocarpa; Lannea* spp. = *Lannea schimperi* and *Lannea velutina;* Ana. = Anacardiaceae; Ann. = Annonaceae; Vit. = Vitaceae; Rut. = Rutaceae; Con. = Connaraceae; Mor. = Moraceae; Ica. = Icacinaceae; Apo. = Apocynaceae; Rub. = Rubiaceae; Ver. = Verbenaceae; Ola. = Olacaceae

**In the same column, values followed by different letters are significantly different ($P < 0.05$) according to the Student-Newman-Keuls test in SAS (2003).

****C. silvestr.* = *C. silvestrii; C. punct.* = *C. punctata; F. caudat.* = *F. caudatus; F. silvestr.* = *F. silvestrii; F. des.* = *Fopius desideratus; Diach*. spp. = *Diachasmimorpha fullawayi* and *D. carinata*; My = May; Jn = June; Jl = July; Au = August; Sp = September; Jn–Au = June to August.

Table 2. Number (No.) and percentage (%) of fruit fly and parasitoid species recovered from various fruit species in Casamance in 2010.

Fruit plants	Fruit fly species								Parasitoid species*											
	B. invadens		*C. cosyra*		*C. silvestrii*		*C. punctata*		*F. caudatus*		*F. silvestrii*		*F. desideratus*		*Diach.* spp.		*P. cosyrae*		*P. concolor*	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
A. occidentale	124	93.2	9	6.8	0	0	0	0	0	0	0	0	6	100	0	0	0	0	0	0
A. senegalensis	155	2.6	5807	95.9	92	1.5	2	0.03	23	59.0	3	7.7	10	25.6	2	5.1	1	2.6	0	0
I. senegalensis	1	0.1	1121	90.3	119	9.6	0	0	64	66.7	18	18.7	2	2.1	10	10.4	0	0	2	2.1
L. dulcis	1	0.1	9	1.2	0	0	749	98.7	5	33.3	0	0	0	0	7	46.7	3	20	0	0
S. comorensis	0	0	1	33.3	0	0	2	66.7	0	0	0	0	1	100	0	0	0	0	0	0
S. latifolius	10	0.4	2489	98.9	0	0	18	0.7	153	67.7	33	14.6	14	6.2	19	8.4	7	3.1	0	0
Parasitoids recovered from all fruit species									245	64.0	54	14.1	33	8.6	38	9.9	11	2.9	2	0.5

**Diach.* spp. = *Diachasmimorpha fullawayi* and *D. carinata*.

Bruce yielded both fruit flies and parasitoids; no fruit flies or parasitoids were recovered from 10 fruit species (Table 1). Seven species of parasitoids belonging to three genera in the same family of Hymenoptera (Braconidae) were reared from the samples (Tables 1 and 2). They were: *Fopius caudatus* Szépligeti, *Fopius silvestrii* Wharton, *Fopius desideratus* Bridwell, *Diachasmimorpha fullawayi* Silvestri, *Diachasmimorpha carinata* (Szeligeti), *Psyttalia cosyrae* Wilkinson and *Psyttalia concolor* Szépligeti. The most abundant parasitoid was *F. caudatus* (63.97 %) (of a total number of 383 parasitoids), followed by *F. silvestrii* (14.10 %) (Table 2).

Fopius caudatus, D. fullawayi, P. cosyrae and *P. concolor* were reported from West Africa (Silvestri 1913; Vayssières *et al.* 2011a) and from several other countries in West-Central Africa. *F. silvestrii* was originally described by Wharton (1987) from West Africa (Togo) and Central Africa (Cameroon). *Diachasmimorpha carinata* has been reared from ceratitidine and dacine tephritids, with nearly all records published under the name *D. giffardii*, a junior subjective synonym of *carinata* (Wharton 1987). *D. giffardii* was described from Conakry, so this species has been already reported from West Africa by Silvestri and subsequent collectors. This last species was also recently reared from several hosts in Kenya (Copeland *et al.* 2009). Thus, most of the parasitoids species reared in the current studies have been reported from West Africa. To our knowledge, what was known of the fruit fly parasitoid fauna in Senegal before this study may be listed as *Diachasmimorpha fullawayi* (Silvestri 1912), *Psyttalia dexter* (Silvestri 1913), *Coptera silvestrii* (Yoder & Wharton 2002; Silvestri 1914). Among parasitoids reared in the current study, only *D. fullawayi* was reported before in Senegal, indicating that this is the first report in the country of *D. carinata, F. caudatus, F. silvestrii, F. desideratus, P. cosyrae* and *P. concolor*.

Members of *Fopius* species, including *F. desideratus,* were reported to be very similar to one another, differing primarily in colour (Wharton 1987). Members of this group of species have been collected from Cameroon and Nigeria east to Kenya and Tanzania as well as South Africa and Madagascar, and undoubtedly occur throughout sub-Saharan Africa (Wharton 1987). Most, but not all of the specimens reared to date have been from *Dacus*-infested Cucurbitaceae. The few remaining records were from ceratitidine tephritids

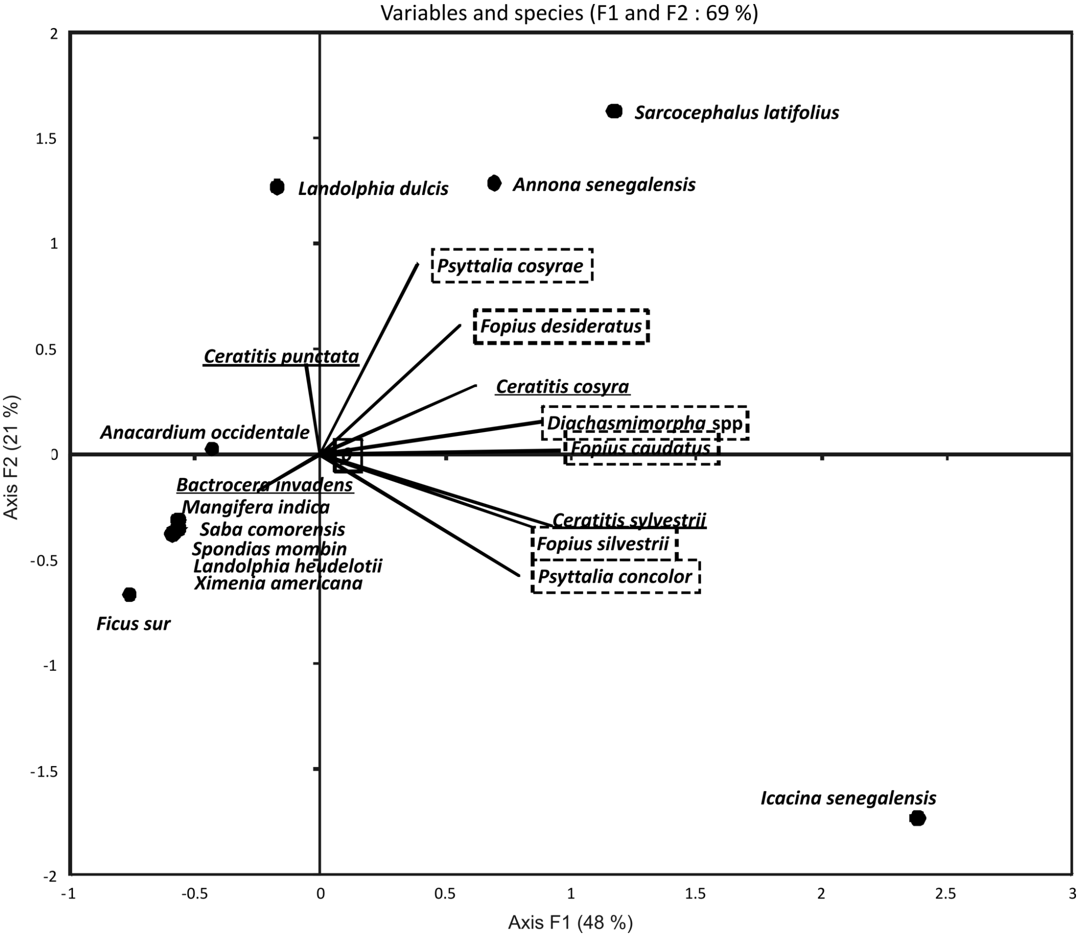

Fig. 1. Principal component analysis performed taking into account hosts (●), fruit fly species (underlined) and parasitoid species (boxed) collected in Casamance in 2010. *Diachasmimorpha* spp. = *D. fullawayi* and *D. carinata.*

on various hosts (Wharton 1987). In the current survey, *F. desideratus* individuals were reared from different plant species (including *A. occidentale, A. senegalensis, I. senegalensis, S. comorensis* and *S. latifolius)* mostly infested by ceratitidine tephritids (Tables 1 and 2). The *Psyttalia* species reared in this current survey include *P. cosyrae* (long-ovipositor forms) and *P. concolor*. In fact, there are several species of *Psyttalia* in the Sub-Saharan region that are difficult to differentiate (Rugman-Jones *et al.* 2009) due mainly to a combination of size, colour and punctations on the body of these species. They are those species that are reared from or attack fruit flies of the *Trirhithrum* species such as *T. coffeae* and *T. nigerrimum.* These flies are relatively smaller and infest smaller fruits like coffee berries and others in the family Rubiaceae (but not exclusively limited to this family). These flies are mostly dark-coloured or black, and the parasitoids that attack these flies usually look darker than those that attack the *Ceratitis* species. They usually have shorter ovipositors, which have evolved with the size of fruits from which they find their preferred host flies and have punctations on the thorax. As a result, they are somewhat darker and can easily be separated from the more orange or yellowish other 'small' *Psyttalia* species. Those that attack deep-seated larvae in bigger fruits like mangoes and cucurbits are those with the relatively long ovipositors like *P. phaeostigma* and *P. cosyrae* (Billah *et al.* 2005). In a previous survey conducted in Benin, some species of reared *Psyttalia* had shorter ovipositors and were called *P. perproxima* (Vayssières *et al.* 2011a). This species was originally described from Benin from fruits infested by tephritids (Silvestri 1913). Thus, because the species of *Psyttalia* are difficult to discriminate, it is possible that more than two species of *Psyttalia* are included in our current samples, including either *P. perproxima* or the nearly identical *P. humilis* (Silvestri) (Rugman-Jones *et al.* 2009).

In the current survey, the reared parasitoid species seem to have fruit species preferences. For instance, *F. caudatus* and *D. fullawayi* were never recovered from *A. occidentale* or from *S. comorensis,* while *P. concolor* was recovered only from *I. senegalensis*. Out of the 383 individual parasitoids recovered from fruit fly pupae, the most abundant species was *F. caudatus* (Table 2), similar to earlier records in Benin by Vayssières *et al.* (2011a). The *Fopius* genus is more abundant (86.7 %) followed by the *Diachasmimorpha* genus (9.9 %). The *Psyttalia* genus (3.4 %) was the least abundant. Despite the numerous fruit fly species recovered from fruits in the current survey, *Fopius* species, especially *F. caudatus*, were most frequently recovered from *C. cosyra*-infested fruits, followed by the other *Ceratitis*-infested fruits (Table 2). It was also noticed that the higher the density of *C. cosyra* in the fruit samples, the greater the number of *F. caudatus* recovered. There was a significantly positive correlation ($r = +0.83$, $P = 0.045$) between numbers of *C. cosyra* and those of *F. caudatus*. Although *B. invadens* was recovered in *A. occidentale* at more than 90 % and *C. cosyra* at less than 7 %, no *F. caudatus* was recovered from that fruit – only *F. desideratus* was recovered. This latter parasitoid was recovered from fruit samples that yielded mostly *C. cosyra*. No parasitoids were recovered from fruit samples infested by *B. invadens* alone. In samples infested by *B. invadens* and at least one other fly species, *F. desideratus* was the most common parasitoid when *B. invadens* was most abundant and *F. caudatus* was the most common parasitoid when *C. cosyra* was most abundant. Based on these data, it is likely that *F. caudatus* attacked only *Ceratitis* species in fruits infested by several species.

Factors such as fruit species (Tables 1 and 2) and fruit season (Table 1) determine the fruit fly infestation rates as well as the occurrence and parasitism level of the parasitoid species. A principal component analysis performed on the interactions between hosts, fly species and parasitoid species (Fig. 1) confirmed no parasitoid species emerged from *B. invadens* puparia. The *I. senegalensis* fruit, which was mostly infested by *C. silvestrii*, seemed to harbour all recovered parasitoid species, except *P. cosyrae*. Similarly, *S. latifolius* and *A. senegalensis*, which were mostly infested by *C. cosyra*, seemed to harbour *Fopius* species, *Diachasmimorpha* species and *P. cosyrae*. Though the significantly ($P = 0.045$) highest infestation rate (752.2 ± 12.6) was recorded in *A. senegalensis,* even though the parasitism rate was only 0.64 % on the fruit. Four fruit fly species were recovered from fruit samples, including *B. invadens, C. cosyra, C. silvestrii* and *C. punctata* (Tables 1 and 2). Data in the current survey suggest that, although fruit flies were recovered from fruits from May to September, parasitoid occurrence was from June to August, depending on the species (Table 1). This period coincides with the peak of the rainy season and with the maturity period of the surveyed crops, including mango. This information is of paramount importance for not only could it help avoid interspecific competition, and also in terms of the introduction of exotic parasitoids, which could take this occurrence or favourable period into account for a successful establishment of the parasitoids as biocontrol agents against fruit flies in mango orchards.

The overall mean parasitism level was 2.4 ± 1.3 %, with no parasitism from many fruits, including mango. This level, however, is way above the low level of 0.020 ± 0.003 % reported from previous survey in mango from Benin (Vayssières *et al.* 2011a). Previous hypotheses have attributed low rates of parasitism partly to physical difficulties in locating immature stages of fruit flies in certain fruits (Sivinski *et al.* 2000). Our results showed no parasitism from 70 % of the surveyed fruits, including cultivated fruits. Of the parasitoids reared from the fruits, the highest parasitoids were mostly recorded from wild fruits such as *I. senegalensis, A. senegalensis* and *S. latifolius*. In fact, cultivated crop species such as mango orchards may constitute unfavourable conditions due to human interventions (cultural practices, insecticide application) that negatively impact parasitoids, and is consistent with the report from Hernández-Ortiz *et al.* (2006). These authors attributed the low level of parasitism observed in their study to probable orchard management practices, in which periodic pesticide use could have a negative impact on parasitoid populations. Studies carried out in Brazil reported similar species diversity and levels of parasitism (Uchôa-Fernandes *et al.* 2003). In either case, our data are consistent with earlier findings concerning parasitoid abundance in wild and cultivated settings (Sivinski *et al.* 2000; Hernández-Ortiz *et al.* 2006; Vayssières *et al.* 2011a), and indicate a host habitat preference for the wild fruit habitat for the dominant parasitoid species reported here. Higher infestation levels in wild fruits can serve as a source of infestations in cultivated fruits at least seasonally. However, these wild plants are also a potential reservoir for the development of parasitoids throughout the year.

In a given fruit crop production area, there is always a diverse assemblage of native fruit fly parasitoids, and our samples indicate that the Casamance region is not an exception. Yet, the efficacy of this parasitoid assemblage in controlling tephritid pests is low as indicated by the high infestation levels compared to the lower parasitism levels. The most abundant species, *F. caudatus*, generally exhibited low levels of parasitism overall, and was not recovered from the exotic pest *B. invadens*. This very low level of parasitism by native parasitoids may justify the introduction of non-native species such as *F. arisanus*, that is known to be effective in limiting the population of many *Bactrocera* spp. (Rousse *et al.* 2006), including members of the *B. dorsalis* complex. For example, *F. arisanus* has been introduced for a classical biological control programme by CIRAD (International Centre of Agricultural Research for Development) into Réunion against *Bactrocera zonata* (Saunders) (Quilici *et al.* 2005). Most recently, *F. arisanus* showed good effectiveness after its introduction to Tahiti (Vargas *et al.* 2007) against *B. dorsalis*. *Fopius arisanus* has been reported to be able to parasitize 21 tephritid species in the laboratory and to develop, with variable successes, on 18 of them (Rousse *et al.* 2006). Therefore, *F. arisanus* could represent a promoting biocontrol agent against some damaging fruit flies in West Africa, especially against *B. invadens*.

CONCLUSION

One of the needs for sound biological control is a better understanding of the ecology and host utilization of biological control agents in their native environments. This study in Casamance is just a preliminary step. After Silvestri (1913), this is the second study on the inventory of parasitoid species from cultivated and wild fruit crops in Senegal. Recovery of *D. carinata, F. caudatus, F. silvestrii, F. desideratus, P. cosyrae, P. concolor* is the first report of the species in Senegal, and the study also provides critical baseline data for future conservation actions or implementation of biological control or IPM programmes in Senegal against *B. invadens.*

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