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Seasonality and range of fruit fly (Diptera: Tephritidae) host plants in orchards in Niayes and the Thiès Plateau (Senegal)

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Seasonality and range of fruit fly (Diptera: Tephritidae) host plants in orchards in Niayes and the Thiès Plateau (Senegal).

Abstract – Introduction. Senegal produces up to 150,000 t of fruit, of which 60,000 t are mangoes. Fruit production is important for the Niayes region, where 60% of total production is of mangoes, with citrus production coming next at 24%. Mango losses have become more substantial since the arrival of *Bactrocera invadens* in Senegal. The pest population increases in the mango ripening period, but little is known about its secondary hosts. **Materials and methods.** Fruits of cultivated and wild plants were collected regularly from April to December 2008 inside and around 19 orchards in eleven localities in the Niayes and Thiès areas in Senegal. The samples were monitored to identify any fruit flies present so that a list of host plants could be compiled. For mango, the study focused on establishing the influence of certain parameters such as the variety, the fruit size, the color, the flowering pattern and the physiological levels of infestation due to *B. invadens* and *Ceratitis cosyra*. Orchards were classified either as traditional (many mango varieties and many fruit species grown together in a stand) or intensive (fields of monovarietal mango trees), according to their composition and how they were managed. **Results and discussion.** A total of 663.2 kg of fruit, including those of 24 mango varieties, 13 citrus species with five lime varieties, two orange varieties and four pomelo varieties along with other cultivated and wild plants, were sampled both as fallen fruit and from the trees. Traditional orchards were more infested than the modern ones. *B. invadens* was significantly dominant over the other flies emerging such as *C. cosyra*, *C. capitata*, *C. punctata*, *C. breinii*, *Bactrocera cucurbitae*, *Capparimyia bipustulata*, *Carpomyia* sp. and *Dacus* sp. *B. invadens* was found on the 24 varieties of *Mangifera indica*, the 13 citrus species, and the other cultivated plants and wild plants sampled. Some host plants supported a relatively high level of fruit flies before the mango ripening period. *Mangifera indica* was infested principally by *B. invadens* and *C. cosyra*. *C. cosyra* was significantly present on the first fruit trees to flower, mostly in early varieties, while *B. invadens* infested all the varieties whatever the fruit development stage, the color, or the flowering pattern. **Conclusion.** Because of the host plants' diversity and varieties the traditional orchards were more infested than the modern ones. The management of this pest needs an Integrated Pest Management system based on a back-to-basics study of the infesting fruit flies, existing parasitoids and their hosts.

Senegal / fruit crops / host plants / *Mangifera indica* / Citrus / Tephritidae / *Bactrocera invadens* / *Ceratitis cosyra* / orchards / sampling

Saisonnalité et gamme des mouches des fruits (Tephritidae, diptères) identifiées dans les plantes hôtes des vergers des Niayes et du plateau de Thiès (Sénégal).

Résumé – Introduction. La production fruitière du Sénégal est estimée à 150.000 t dont 60.000 t de mangues. Les agrumes représentent 24 % de cette production et se situent en seconde position après la mangue qui représente 60% de la production fruitière très importante dans les Niayes. Depuis l'arrivée de *Bactrocera invadens* au Sénégal les pertes de production de mangues ont augmenté. Les populations du ravageur sont importantes en période de maturation des fruits mais les informations concernant ses hôtes secondaires sont rares. **Matériel et méthodes.** Les fruits d'espèces fruitières cultivées et spontanées ont été collectés régulièrement d'avril à décembre 2008, dans et autour de 19 vergers de onze localités de la zone des Niayes et du plateau de Thiès (Sénégal). Ces fruits ont été suivis pour déterminer les espèces de mouches hébergées et répertorié ainsi leurs plantes hôtes. Chez la mangue, l'étude a cherché à montrer l'influence de paramètres tels que la variété, la taille du fruit, la couleur, la vague de floraison ou l'état physiologique sur les infestations par *B. invadens* et *Ceratitis cosyra*. En fonction de leur composition et de leur mode de conduite, les vergers ont été classés en deux types : traditionnel (plusieurs variétés de manguiers et plusieurs espèces fruitières cultivées à la fois au sein d'une même parcelle) ou moderne (parcelles monovariétales de manguiers). **Résultats et discussion.** Au total, 663,2 kg de fruits issus de 24 variétés de manguiers, 13 espèces d'agrumes, dont 5 variétés de limetier, 2 variétés d'orangers et 4 variétés de pomélos, ainsi que d'autres espèces fruitières cultivées ou spontanées, ont été échantillonnés soit au sol, soit sur l'arbre. Les vergers de type traditionnel ont été plus infestés que les vergers de type moderne. Parmi les Tephritidae issues des fruits collectés, l'espèce *B. invadens* a été significativement dominante sur *Ceratitis cosyra*, *C. capitata*, *C. punctata*, *C. breinii*, *Bactrocera cucurbitae*, *Capparimyia bipustulata*, *Carpomyia* sp. et *Dacus* sp. L'espèce *B. invadens* a été retrouvée chez 24 variétés de *Mangifera indica*, 19 cultivars d'agrumes, et chez d'autres espèces fruitières cultivées et spontanées. Certaines plantes hôtes ont maintenu des niveaux de populations de *B. invadens* avant la période de maturation de la mangue. Le manguiers est principalement infesté par *B. invadens* et *C. cosyra*. L'espèce *C. cosyra* est significativement importante dans les fruits issus des premières vagues de floraison et surtout chez les variétés précoces, tandis que *B. invadens* est présente dans toutes les variétés quels que soient l'état du fruit, sa couleur, la vague de floraison et l'endroit de collecte. **Conclusion.** Du fait de la diversité des plantes hôtes et des variétés, les vergers traditionnels ont été plus infestés que les vergers modernes. La gestion de ce ravageur nécessite de définir un système de lutte intégrée basée sur une étude de base des mouches des fruits présentes, des parasitoïdes existants et de leurs hôtes.

Sénégal / plante fruitière / plante hôte / *Mangifera indica* / Citrus / Tephritidae / *Bactrocera invadens* / *Ceratitis cosyra* / verger / échantillonnage

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RESUMEN ESPAÑOL, p. 331

1. Introduction

The Niayes zone is one of Senegal's development hot-spots, with commercialized periurban farming and major anthropization [1]. The region is responsible within the national economic plan for a major share of the estimated national fruit production of 150,000 t-year⁻¹, of which mangoes are about 60% and citrus fruits 24%. It supplies around 80% of the mangoes exported. Thanks to favorable ecological conditions, yields have reached 10 t·ha⁻¹ in the traditional orchards and 20 t·ha⁻¹ in the modern orchards [2]. Productivity and value addition has increased, alongside an improvement in quality, thanks to the increased professionalism in the mango sector. As a result, mango exports to the European Union went up from 280 t in 1998 to 6,410 t in 2006 [2] to rank Senegal in second place to Côte d'Ivoire. Despite this, improving the quality side of mango production remains a major objective because production is penalized by the considerable damage caused by fruit flies (Diptera, Tephritidae) even though there is a recurring pathogen complex in Niayes. These Diptera cause estimated 30–50% damage in the Niayes region and 60% in the Casamance [3].

Only limited studies have been carried out in Senegal on fruit flies. A preliminary inventory of fruit flies in mango orchards was made as part of the joint study by the *Comité de Liaison Europe-Afrique-Caraïbes-Pacifique* (COLEACP), the *Centre de coopération internationale en recherche agronomique pour le développement* (CIRAD), the *Centre Régional de Recherche en Ecotoxicologie et de Sécurité Environnementale* (CERES) and the *Direction de la Protection des Végétaux* (DPV) that identified 18 species; ten of which were *Ceratitidis* species, six species of *Dacus* and two of *Bactrocera* [4]. These last two pest species of great economic importance were identified as *Bactrocera cucurbitae* (Coquillett) on crops of Cucurbitaceae and *Bactrocera invadens* Drew Tsuruta & White on fruit tree crops, while the main *Ceratitidis* species were *Ceratitidis cosyra* (Walker) and *Ceratitidis silvestrii* Bezzi [4]. Before *B. invadens* arrived in Africa, most fruit infestations

recorded in West Africa were linked to *C. cosyra* and *C. capitata* (Wiedemann) [5, 6], but this situation changed completely after. The first studies on the hosts of *B. invadens* were carried out in East Africa [7, 8] and in West [9] and Central [10] Africa.

In our study zone, mango and citrus are the main fruits farmed, with, to a much lesser extent, papaya, guava and banana. The plantations are characterized by the presence of both traditional and intensive orchards. The traditional orchards are essentially dedicated to supplying the home market. The growers try to phase their production to reduce the pathogen risks and to overcome new commercial challenges, so they cultivate several genera, species and varieties of fruit alongside each other on their plots. Irrigation is necessary because the dry season lasts nearly nine months from October to mid-July. Besides the commercial goals, orchard composition is influenced by irrigation capacity.

The intensive orchards are dedicated to exporting mangoes so the blocks contain single species and single varieties grafted on Kent and, less commonly, on Keitt. These exporting producers must have at least 60 ha to be able to send their production for export only. Cropping is mechanized and agrochemical applications follow the specifications demanded to meet certification (GlobalGap, biological agriculture, etc.).

The non-growing exporters collect their mangoes from small growers, as do some exporting producers who need to top up their shipments when their own production falls short. The advent of certification and related higher buying prices have encouraged growers to produce under controlled management for exporting themselves rather than for producing fruit for collection.

The study zone is characterized by scattered orchards in artificial forest stands comprising species to protect the water-holding depressions (*Casuarina equisetifolia* Forst. and *Eucalyptus* sp.) and either self-reproducing fruit species (*Annona senegalensis* Pers.) or introduced trees such as *Terminalia catappa* L. or *Achras sapota* L. The naturalized fruit trees are relatively less

significant both in terms of species and numbers than cultivated fruit trees.

Our study focused mainly on the fruit fly seasonality in different mango and citrus cultivars of commercial interest. A range of secondary host plants was also looked at, such as the Solanaceae (*Lycopersicon esculentum* Mill., *Capsicum annuum* L., *Capsicum frutescens* L.), the Cucurbitaceae [*Cucumis sativus* L., *Cucumis melo* L., *Citrullus lanatus* (Thunb.) Matsum. & Nakai.] and other plants that might cause fluctuations in the Tephritidae populations of the orchards. This study focused particularly on establishing the influence of parameters such as the mango flowering period, variety, fruit location (on the tree or the ground), maturation stage (mature, immature), physiological state (dropped before maturity, damaged or senescent), color and size.

2. Materials and methods

2.1. Study sites

The study was carried out in Senegal, in the Niayes zone and the Thiès Plateau, in 19 orchards chosen by virtue of their accessibility, management, species and varietal diversity, and for the availability of fruit samples (table 1).

Within Niayes, fourteen orchards were picked in nine localities: Notto Gouye Diama, Keur Séga, Bayakh, Sangalkam, Keur Ndiaye Lô, Keur Moussa, Gorom II and Sébikhotane. On the Thiès Plateau, the study took place in five orchards in Peykouck, Pout and Sindia (figure 1).

The Niayes zone, which stretches between 17°26' and 16°15' long. W and 14°



Figure 1. Map of the orchard sites in the Niayes and Thiès plateau zones, in Senegal, where fruits were sampled for identifying fruit fly seasonality.

Table I.

Locations of 19 orchards studied for identifying fruit flies present on fruit trees in the Niayes zone and the Thiès Plateau, in Senegal.

Locations	Number of orchards	Latitude (N)	Longitude (W)
Niayes zone			
Notto gouye Diama	4	14°58'32.3"	17°01'36.2"
		14°58'19.4"	17°01'30.3"
		14°59'05.3"	17°00'17.2"
		14°58'20.3"	17°00'10.3"
Sangalkam	1	14°34'51.9"	17°02'24.7"
Keur Séga	2	14°58'18.9"	17°00'07.8"
		14°58'08.8"	17°00'09.2"
Bayakh	1	14°49'57.8"	17°13'71.5"
Sébikotane	2	14°45'44.7"	17°08'46.6"
		14°45'45.6"	17°09'07.3"
Keur Moussa	2	14°46'29.3"	17°07'31.5"
		14°46'29.8"	17°07'29.9"
Gorom II	1	14°09'07.3"	17°10'00.8"
Keur Ndiaye Lo	1	14°44'53.7"	16°57'12.1"
Thiès Plateau			
Peykouck	1	14°45'56.7"	16°53'28.1"
Pout	1	14°45'37.4"	17°03'18.6"
Sindia	3	14°34'13.0"	17 02'39.9"
		14°34'52.3"	17 02'23.6"
		14°34'08.3"	17 03'17.0"

to 15°56' lat. N, lies between the 500-mm isohyet in the south towards Dakar and the 350-mm isohyet in the north towards Saint-Louis. The zone is characterized by non-lesive tropical ferruginous soils, crude mineral soils, red-brown soils, halomorphic soils, and pseudo-gley mineral soils in the lowlands [11]. The surface layer varies down to 30 m [12]. The Niayes zone is part of the Sahel-Sudanian region. Its vegetation is influenced by the topography, the soils

present and water availability. Plant cover is dominated by plantations (*Casuarina equisetifolia* Forst.) protecting basins, and naturally occurring clumps of *Elaeis guinensis* Jacq., *Cocos nucifera* L., *Mezoseurum benthamianum* Baill. and hygrophilic species [*Nymphaea lotus* L., *Phragmites vulgaris* (Lam.) Druce., *Alchornea cordifolia* (S. et Th.) Müll. Arg.] on the highly humid lowlands; by *Parinari macrophylla* Sabine, *Faidherbia albida* (Del.) Chev., *Acacia*

seyal Del., *Balanites aegyptiaca* (L.) Del.; with Euphorbiaceae, Combretaceae and graminaceous plants such as *Cenchrus biflorus* Roxb., *Andropogon* sp., *Eragrostis* sp. on the red ocher dunes (Ogolien); and by *Opuntia tuna* (L.) Mill., *Maytenus senegalensis* (Lam.) Exell. on the yellow and white dunes [13].

The Thiès Plateau, with substantial mango plantations, belongs to Senegal's Groundnut Basin where the soils are tropical ferruginous, either gray-brown podzolic or slightly gray-brown podzolic. This results in a pedoclimatic zone of continental rise and plains with a marno-calcareous soil, in turn creating a series of hydromorphic ferruginous soils over marno-calcareous colluvial material with either sandy-clay or clayey-sand surface horizons. The water table is tapped easily, while rainfall is from 400 mm up to 600 mm. Vegetation comprises mostly *Khaya senegalensis* (Desr.) A. Juss. and *Eucalyptus* sp. in the plantations in Bandia, with natural stands in Pout, Thiès, Bandia and the communal reserve in Popen-guine composed of *Acacia seyal* Del., *Faidherbia albida* (Del.) Chev., *Acacia ataxacantha* DC., *Combretum* sp., *Borassus aethiopum* Mart., *Guiera senegalensis* J.F. Gmel. and *Adansonia digitata* L. This fertile zone lends itself to reforestation and mixed cropping [14]. The mango varieties are sometimes the rootstock of polyembryonic varieties that self-disseminate, such as Boucodiékhil, Dieg bou gatt or Séwé, and sometimes grafted cultivars, the most frequently found of which were Kent, Keitt, Amélie and Paheri (known locally as Pêche). Cultivars such as Palmer, Haden and Colombo are encountered occasionally. But there are many intermediate levels between the big export-oriented plantations and the little orchards that cater for the local market: big plantations looking to the national or sub-regional markets; little orchards of Kent for sale to exporters or traders; the little mango plantations receiving little or no maintenance; or, on the other hand, the small plantations taking tremendous care with a range of strongly performing species and varieties, etc.

The varietal composition of orchards is one of the main differences between the tra-

ditional and intensive. Traditional orchards are often bounded by hedges of *Euphorbia turicali* L., *Euphorbia balsamifera* Ait. or *Capparis tomentosa* Lam. Infrequent weed clearance encourages wild Cucurbitaceae such as *Kedrostis birtella* Cogn., *Momordica balsamina* L., *Momordica charantia* L. or *Collocynthus* sp.

2.2. Fruit tree species sampled

The phenology of the fruit trees was surveyed to determine their production periods. Following the orchards surveyed, ten fruits per sample were collected weekly from April to December 2008, either from the ground or by picking from several fruit tree species, depending on their production periods. These fruit tree species were mango (*Mangifera indica* L.), citrus species [*Citrus aurantium* L., *C. aurantifolia* (Christm.) Swing., *C. maxima* L., *C. paradisi* Macfad., *C. clementina* Hort. Ex Tan., *C. reticulata* Blanco, *C. limon* (L.) Burm. F., *C. sinensis* (L.) Osbeck, *C. deliciosa* Tan., *Fortunella japonica* Swing., *F. margarita* Swing.], other introduced trees [*Psidium guajava* (L.), *Eugenia uniflora* L., *Phoenix dactylifera* L., *Terminalia catappa* L., *Phyllanthus acidus* (L.) Skeel.] and local species [*Saba senegalensis* (A. DC.) Pichon., *Cordyla pinnata* (Lepr.) Miln.-Red., *Kedrostis birtella* Cogn., *Ziziphus mauritiana* Lam., *Sclerocarya birrea* (A. Rich.) Hochst., *Spondias mombin* L., *Capparis tomentosa* Lam., *Momordica balsamina* L., *Cucumis sativus* L.]. Some species comprised several identified varieties, e.g., twenty-four varieties for *Mangifera indica*, six cultivars for *Citrus aurantifolia*, four cultivars for *C. paradisi*, and two cultivars for *C. sinensis*. The fruits from each sample were weighed and their dimensions were taken before being classed by size as 0–5 cm, 5–10 cm, 10–15 cm and 15–20 cm. Classification also took account of color, fruit condition, sampling location and the flowering date of the mango.

2.3. Fruit monitoring

The weighed and classified fruits were incubated over a substrate of sieved coarse sand in pots firmly covered with cloth to prevent

the escape of any larvae or imagoes as well as to keep out ants or spiders. The number of fruits in samples varied according to species and their on-site availability; so the average was (7.2 ± 1.2) fruits for mango, (13.4 ± 1.8) fruits for citrus, (15.1 ± 1.1) fruits for cashew, and (25.5 ± 1.0) fruits for capers.

After one to three weeks of incubation, any pupae found were placed in Petri dishes and their emergence monitored so they could be identified and counted by species and sex, and indexed by sample following designated parameters.

The various fruit samples were collected in the selected orchards from April to December 2008 to cover the flowering, setting, bulking and maturing of the mangoes from one production season through to the onset of flowering in the next. The observations made during field sampling covered the weight and size of fruit, its condition; the number of pupae extracted per sample, the number of Tephritidae by species and sex, and the number of parasitoids on the pupae.

2.4. Statistical analyses

The data were processed using Microsoft Excel and XL Stat for the analysis of variance and mean comparisons. The ANOVAs for mango in relation to emergence of *B. invadens* and *C. cosyra* took particular account of various parameters such as the flowering pattern prior to mango production, where sampling was taken from, size, skin color, condition and variety. The percentage incidence of *B. invadens* and *C. cosyra* was calculated for each mango variety using the formula $\{[a / (a + b)] \times 100\}$ in which *a* is the number of individuals of *B. invadens* and *b* is the number of individuals of *C. cosyra* in a sample.

3. Results

3.1. Production periods for orchard fruit plants

Fruits are present in the orchards from April to December (*table II*). These are fruits both from cultivated and naturally occurring

plants. Therefore, *Carica papaya*, *Fortunella* sp., *Citrus paradisi* and *Momordica balsamina* bear fruit throughout the duration of the study period while others have seasonal production only: *Mangifera indica*, *Capparis tomentosa*, etc.

3.2. Tephritidae species found in the host fruits

The orchard visits collected a total of 7,290 fruits of mixed species, weighing 663.2 kg equally distributed between Niayes and the Thiès Plateau, 59% of which were mangoes and 28% citrus. The remaining 13% were the products of the other cultivated and self-seeded plants. The pot incubation of these fruits produced 37,276 pupae from which emerged 22,972 fruit flies subdivided into 52% females and 48% males. At the same time, the emergence of 122 parasitoids (Braconidae) of fruit flies was recorded. The emergence of fruit fly species by host plant was assessed (*table III*). Certain species of Tephritidae, *i.e.*, *Bactrocera invadens*, *B. cucurbitae*, *Dacus* spp., *Ceratitidis capitata*, *C. cosyra* and *Carpomyia* spp., were found on several host plants. The polyphagous species *B. invadens* emerged from many of the fruit tree species found in and around the orchards in Niayes and on the Thiès Plateau, including *Mangifera indica* (24 varieties), *Anacardium occidentale* L., *Sclerocarya birrea* (Anacardiaceae), *Terminalia catappa* (Combretaceae), *Capparis tomentosa* (Capparidaceae), *Ziziphus mauritiana* (Rhamnaceae), *Psidium guajava*, *Eugenia uniflora* (Myrtaceae), *Annona muricata* (Annonaceae), *Kedrostis birtella* (Cucurbitaceae), *Carica papaya* (Caricaceae), *Cordyla pinnata* (Cesalpiniaceae), *Phoenix dactylifera* (Palmaceae), *Achras sapota* (Sapotaceae), *Saba senegalensis* (Apocynaceae), *Passiflora edulis* Sims (Passifloraceae) and 13 citrus species. Among the citrus, the genus *Fortunella* showed up as more susceptible to *B. invadens* than members of the genus *Citrus* ($P < 0.0001$) such as *C. aurantium*, *C. aurantifolia*, *C. clementina*, *C. deliciosa*, *C. reticulata*, *C. limon*, *C. paradisi*, *C. sinensis* and *C. maxima* (Rutaceae). This susceptibility was more marked for *F. japonica* than for *F. margarita*.

Table II.

Production periods from April to December 2008 for the main fruit trees studied for identifying fruit flies present in orchards of the Niayes and Thiès Plateau zones, in Senegal.

Fruit species	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
<i>Achras sapota</i>			←						→
<i>Anacardium occidentale</i>	←						→		
<i>Annona muricata</i>			←						→
<i>Annona senegalensis</i>			←						→
<i>Capparis tomentosa</i>	←						→		
<i>Carica papaya</i>	←								→
<i>Citrullus lanatus</i>				←					→
<i>Citrus aurantifolia</i>			←						→
<i>Citrus aurantium</i>				←					→
<i>Citrus clementina</i>				←					→
<i>Citrus deliciosa</i>				←					→
<i>Citrus limon</i>				←					→
<i>Citrus maxima</i>					←				→
<i>Citrus paradisi</i>	←								→
<i>Citrus sinensis</i>			←						→
<i>Fortunella japonica</i>	←								→
<i>Fortunella margarita</i>	←								→
<i>F. japonica</i> × <i>C. aurantifolia</i>				←					→
<i>C. reticulata</i> × <i>C. paradisi</i>								←	→
<i>C. reticulata</i> × <i>C. sinensis</i>								←	→
<i>Cordyla pinnata</i>					←	→			
<i>Cucumis metuliferus</i>								←	→
<i>Cucumis sativus</i>								←	→
<i>Eugenia uniflora</i>						←			→
<i>Jatropha curcas</i>					←	→			
<i>Kedrostis hirtella</i>		←							→
<i>Mangifera indica</i>	←								→
<i>Momordica balsamina</i>	←								→
<i>Parinari macrophylla</i>	←								→
<i>Passiflora edulis</i>								←	→
<i>Persea americana</i>					←	→			
<i>Phoenix dactylifera</i>					←	→			
<i>Phyllanthus acidus</i>					←	→			
<i>Psidium guajava</i>				←					→
<i>Saba senegalensis</i>			←						→
<i>Sclerocarya birrea</i>				←					→
<i>Solanum ethiopicum</i>								←	→
<i>Spondias mombin</i>					←	→			
<i>Spondias purpurea</i>					←	→			
<i>Terminalia catappa</i>					←				→
<i>Ziziphus mauritiana</i> var. <i>gola</i>					←				→

Table III.

Breakdown of Tephritidae species by host plant found in orchards of the Niayes and Thiès Plateau zones, in Senegal.

Host plants	<i>Bactrocera invadens</i>	<i>Ceratitis cosyra</i>	<i>Ceratitis capitata</i>	<i>Carpomyia</i> sp.	<i>Capparimyia bipustulata</i>	<i>Dacus</i> sp.	<i>Bactrocera cucurbitae</i>	<i>Ceratitis punctata</i>	<i>Ceratitis breinii</i>	Quantity of fruits (kg)
<i>Achras sapota</i>	*	*	–	–	–	–	–	–	–	4.2
<i>Anacardium occidentale</i>	*	–	–	–	–	–	–	–	–	10.9
<i>Annona muricata</i>	*	–	–	–	–	–	–	–	–	1.7
<i>Annona senegalensis</i>	*	–	–	–	–	–	–	–	–	0.1
<i>Capparis tomentosa</i>	*	*	*	–	***	–	–	–	–	6.7
<i>Capsicum annuum</i>	*	–	**	–	–	–	–	–	–	0.8
<i>Carica papaya</i>	*	–	–	–	–	–	–	–	–	12.0
<i>Citrullus lanatus</i>	–	–	–	–	–	*	*	–	–	9.3
<i>Citrus aurantifolia</i>	*	–	–	–	–	–	–	–	–	34.4
<i>Citrus aurantium</i>	*	–	–	–	–	–	–	–	–	6.7
<i>Citrus clementina</i>	*	*	–	–	–	–	–	–	–	11.8
<i>Citrus deliciosa</i>	*	–	–	–	–	–	–	–	–	14.3
<i>Citrus limon</i>	*	–	–	–	–	–	–	–	–	13.4
<i>Citrus maxima</i>	*	–	–	–	–	–	–	–	–	2.0
<i>Citrus paradisi</i>	*	–	*	–	–	–	–	–	–	65.5
<i>Citrus sinensis</i>	*	–	–	–	–	–	–	–	–	11.8
<i>Cordyla pinnata</i>	*	***	–	–	–	–	–	–	*	13.0
<i>Cucumis metiflorus</i>	–	–	–	–	–	–	–	–	–	0.9
<i>Cucumis sativus</i>	–	–	–	–	–	*	**	–	–	1.0
<i>Eugenia uniflora</i>	*	–	–	–	–	–	–	–	–	0.3
<i>Fortunella japonica</i>	***	–	*	–	–	–	–	–	–	3.0
<i>Fortunella margarita</i>	**	–	*	–	–	–	–	–	–	8.2
<i>Jatropha curcas</i>	–	–	–	–	–	–	–	–	–	0.5
<i>Kedrostis hirtella</i>	*	*	–	–	–	**	–	–	–	1.7
<i>F. japonica</i> × <i>C. aurantifolia</i> (limequat)	*	–	–	–	–	–	–	–	–	4.0
<i>Mangifera indica</i>	*	*	–	–	–	–	–	–	–	374.6
<i>Momordica balsamina</i>	*	–	–	–	–	*	*	–	–	1.6
<i>Parinari macrophylla</i>	–	–	–	–	–	–	–	–	–	2.2
<i>Passiflora edulis</i>	*	–	–	–	–	–	–	–	–	0.3
<i>Persea americana</i>	*	–	–	–	–	–	–	–	–	1.1
<i>Phoenix dactylifera</i>	*	–	–	–	–	–	–	–	–	0.5
<i>Phyllanthus acidus</i>	–	–	–	–	–	–	–	–	–	1.3
<i>Psidium guajava</i>	***	–	–	–	–	–	–	–	–	1.5
<i>Citrus reticulata</i> × <i>C. paradisi</i> = Tangélo	*	–	–	–	–	–	–	–	–	2.6
<i>Citrus reticulata</i> × <i>C. sinensis</i> = Tangor	*	–	–	–	–	–	–	–	–	0.5
<i>Terminalia catappa</i>	***	–	–	–	–	–	–	–	–	1.0
<i>Saba senegalensis</i>	*	–	–	–	–	–	–	–	–	1.5
<i>Sclerocarya birrea</i>	*	***	–	–	–	–	–	–	–	1.0
<i>Solanum aethiopicum</i>	–	–	–	–	–	–	–	–	–	0.4
<i>Spondias mombin</i>	*	–	–	–	–	–	–	–	–	0.1
<i>Ziziphus mauritiana</i> var. <i>gola</i>	***	–	–	*	–	–	–	–	–	5.7

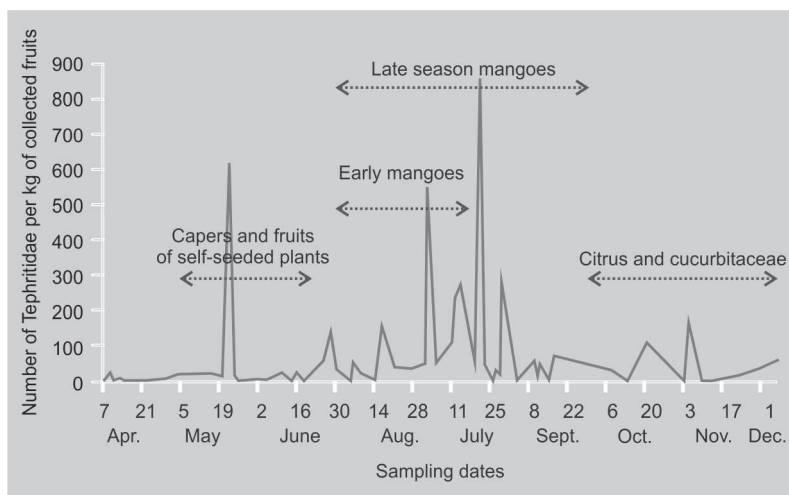
Average emergence values for the collected fruit samples: * ≤100 individuals per kg of fruits, ** 100 < X < 200 individuals per kg of fruits, *** more than 200 individuals per kg of fruits.

The polyphagous species *Ceratitis cosyra* emerged from the fruits of *Achras sapota*, *Citrus clementina*, *Kedrostis birtella*, *Mangifera indica*, *Capparis tomentosa*, *Sclerocarya birrea* and *Cordyla pinnata*.

Ceratitis capitata emerged from the peppers *C. annuum*, *Capparis tomentosa*, and some citrus. *Bactrocera cucurbitae* and *Dacus* spp., which were plentiful on the flowers of *Ziziphus mauritiana* var. *gola*, emerged from the Cucurbitaceae such as *Kedrostis birtella*, *Momordica balsamina*, *Cucumis sativus* and *Citrullus lanatus*. However, other species of Tephritidae were retrieved from single host plants. This was the case for the monophagous species *Ceratitidis breinii* (Guerin-Meneville), *Ceratitidis punctata* (Wiedemann), *Carpomyia* sp. and *Capparimya bipustulata* Bezzi, which were retrieved from, respectively, *Cordyla pinnata*, *Achras sapota*, *Ziziphus mauritiana* var. *gola* and *Capparis tomentosa*.

Certain fruit trees, which harbored several species of fruit fly, were also infested by *Bactrocera invadens*. These were *Capparis tomentosa*, which hosted *Capparimya bipustulata* on top of *B. invadens*, *Ceratitidis cosyra* and *Ceratitidis capitata*; *Ziziphus mauritiana* var. *gola*, which hosted *B. invadens* on top of *Carpomyia* sp.; *C. annuum*, which harbored both *C. capitata* and *B. invadens*; *Mangifera indica* hosted *B. invadens* and *C. cosyra*; while, among the citrus, *Citrus clementina* hosted *B. invadens* and *C. cosyra*; and *Citrus paradisi*, *Fortunella margarita* and *F. japonica* harbored *B. invadens* and *C. capitata*.

With the infestations of *Ziziphus mauritiana* var. *gola* in particular, pupation of the larvae of *Carpomyia* sp. often took place inside the fruit in a cavity tunneled next to the pit so that the fruit looked outwardly healthy. However, fruit infested by 5–10 *Bactrocera invadens* larvae putrefied quickly and more seriously than that affected by the autochthonous *Carpomyia* sp. With *Capparis tomentosa*, on the other hand, the number of *Capparimya bipustulata* is significantly greater than for *Bactrocera invadens* or *Ceratitidis capitata* ($P < 0.0003$).



3.3. Relationship between Tephritidae emergence from the sampled fruit and maturation period of the main host plants

The number of flies emerging from the collected fruits was studied as a function of time and the emergence dynamics correlated to the main host plants' maturation periods (figure 2). This shows that the level of fruit fly emergence from the collected fruits varies in time as a function of the maturing periods of the potential fruit hosts. The peaks are more significant for the maturation of mangoes and relatively significant during citrus maturation.

3.3.1. Dynamics and scale of Tephritidae emergence between orchards on the Thiès Plateau

The results obtained relating to the emergence of the various species of fruit fly were compared as a function of type of orchard, season and site, both in Niayes and on the Thiès Plateau. Studying the progress of *B. invadens* and *C. cosyra* emergence for an orchard in Pout (traditional orchard) and another in Sindia (modern orchard) on the Thiès Plateau (figure 3), it can be seen that, for the Thiès Plateau, emergence between April and mid-July is greater in the traditional type of orchard in Pout than in the modern orchard in Sindia, but this changed later when emergence increased in Sindia. Between April and July, *C. cosyra* is the

Figure 2. Emergence dynamics of fruit flies and the production periods of the main hosting fruit trees in orchards of the Niayes and Thiès plateau zones (2008, Senegal).

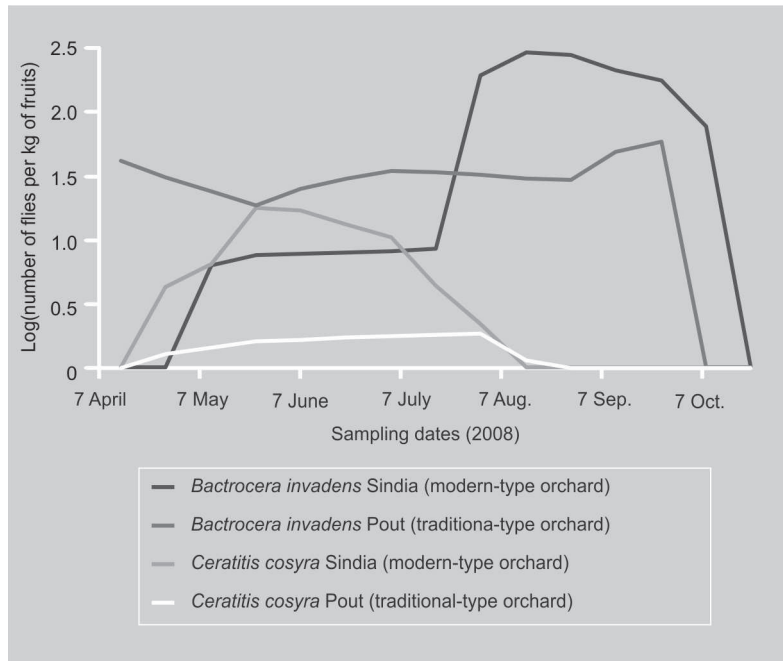


Figure 3. Emergence dynamics for *Bactrocera invadens* and *Ceratitis cosyra* in a traditional-type orchard (Pout) and a modern-type orchard (Sindia) on the Thiès Plateau, Senegal.

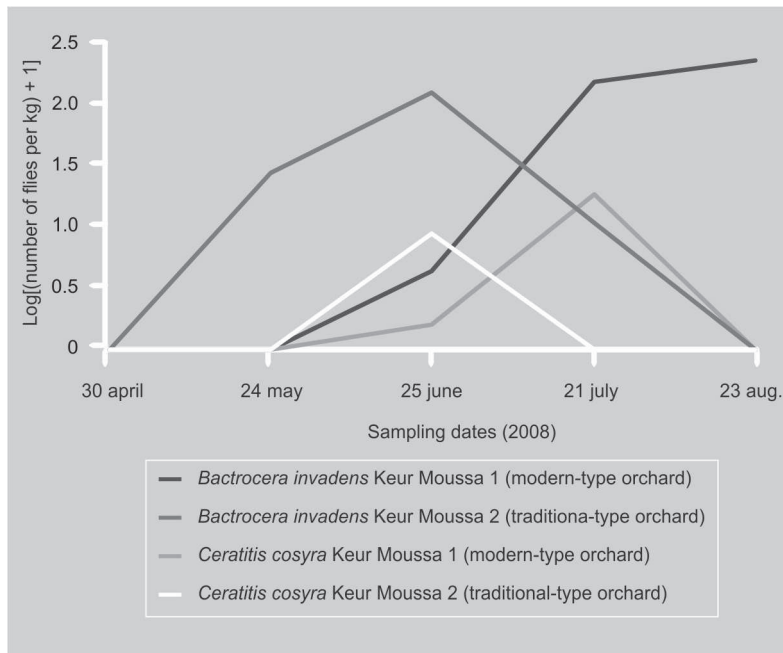


Figure 4. Emergence dynamics for *Bactrocera invadens* and *Ceratitis cosyra* in Keur Moussa in a traditional-type and in a modern-type orchard in the Niayes zone (Senegal).

dominant species in Sindia, while *B. invadens* dominates in Pout. However, *B. invadens* becomes six times more significant in Sindia from July onwards than in Pout. Nevertheless, emergence of *B. invadens* is greater than that of *C. cosyra* ($P < 0.001$) on all the sampling dates in Pout. *Ceratitis cosyra* emergence appears to peak earlier (between May and June) than that of *B. invadens*.

3.3.2. Dynamics and scale of emergence of Tephritidae between orchards in Niayes

The dynamics of the emergence of Tephritidae from fruits collected in the Niayes orchards were analyzed to compare several sites of both traditional-type and modern-type orchards.

The emergence dynamics for *B. invadens* and *C. cosyra* in Keur Moussa for a traditional orchard and a modern orchard showed critical levels of fruit fly emergence in the traditional orchard between April and mid-July, but the modern-type orchard reached its greatest levels of emergence after this date (figure 4). Emergence of *B. invadens* was greater than that of *C. cosyra* in both types of orchard ($P < 0.001$). Among the various observations made across both types of orchard, we noted that populations of *B. invadens* were more precocious in the traditional type of orchard in having a peak outbreak at the end of June against the second two weeks of August for the modern-type orchard.

3.3.3. Tephritidae emergence for different varieties of mango in the traditional and modern orchards

A study comparing the emergence dynamics of the traditional orchard in Pout with that of the modern orchard in Sindia showed the population levels of *B. invadens* to be earlier to peak and more substantial in Pout than in Sindia between April and July ($P < 0.049$). Meanwhile, the *C. cosyra* emergence was greater for the modern orchard in Sindia than in the traditional orchard in Pout ($P < 0.009$). Therefore, emergence varied from one type of orchard to the other

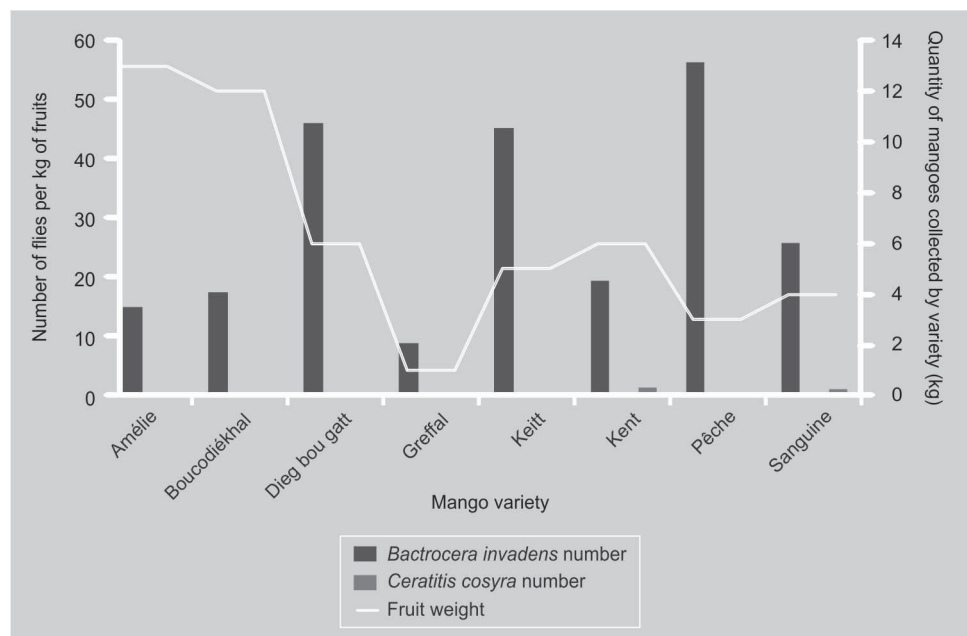


Figure 5. Number of *Bactrocera invadens* and *Ceratitis cosyra* counted by kg of fruits and by mango variety in a traditional-type orchard in Pout (Thiès Plateau, Senegal).

and also within those species present at the times in question.

3.3.3.1. Traditional orchard in Pout

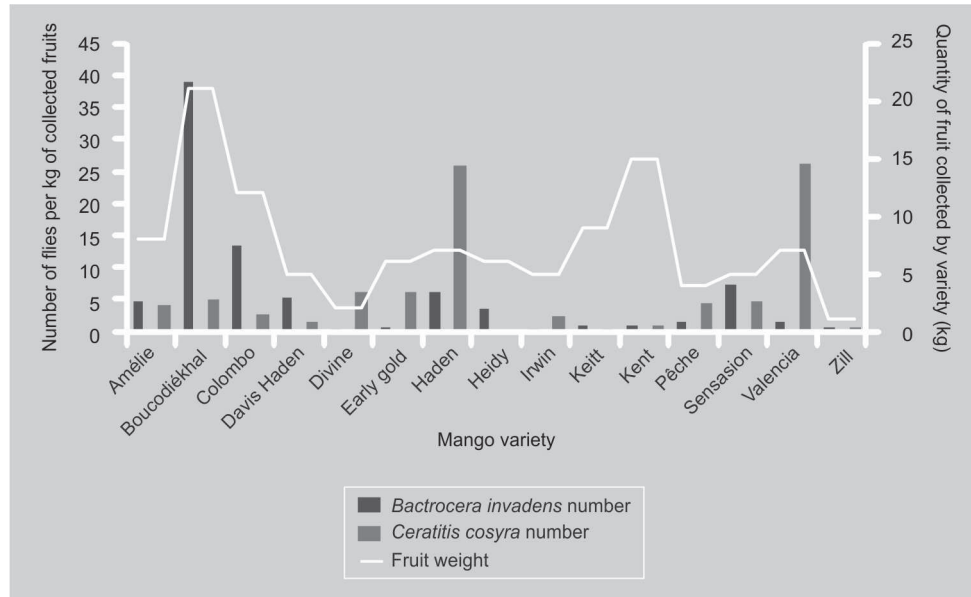
The study also looked at variation in fruit fly species on the varieties of mango collected from each orchard. The number of Tephritidae per kg of fruits collected by mango variety and the quantity of fruit sampled for each variety show that local varieties (Boucodiékhhal, Dieg bou gatt, Greffal) and grafted trees (Amélie, Keitt, Kent, Pêche and Sanguine) grown simultaneously in the traditional orchard in Pout were infested (figure 5). The quantity of fruits collected was greater for Amélie and Boucodiékhhal but all the varieties were more infested by *B. invadens* than by *C. cosyra* ($P < 0.0001$). The varieties Pêche, Dieg bou gatt, Keitt, Sanguine, Kent and Boucodiékhhal seemed to have greater infestations than Amélie and Greffal ($P < 0.001$). There was no significant difference between the varieties Keitt and Dieg bou gatt, on one hand, and between Kent and Boucodiékhhal, on the other hand ($P = 0.719$), although *B. invadens* emergence remained greater than that of *C. cosyra* ($P < 0.0001$).

3.3.3.2. Modern orchard in Sindia

A block in the Sindia orchard containing several mango varieties was monitored from before the maturation period of the early varieties through to the end of the late types Boucodiékhhal, Keitt and Kent. The average number of Tephritidae by species and per kg of fruits collected of each variety in this orchard and the total quantity of fruits noted for each mango variety showed that the varieties Boucodiékhhal, Haden and Valencia were significantly more infested than the cultivars Keitt, Kent, Irwin, Heidy, Early Gold, Pêche and Divine, while Amélie, David Haden, Sensation and Colombo were classed as intermediate (figure 6). The percentage infestation by *B. invadens* and by *C. cosyra* was calculated for each variety, revealing that the varieties David Haden, Keitt, Colombo, Boucodiékhhal and Heidy were infested in more than 75% of instances by *B. invadens*, while *C. cosyra* infested the varieties Divine, Irwin, Valencia, Early Gold, Pêche and Haden in more than 75% of cases.

In the modern orchard in Sindia, there is no significant difference in the numbers of *C. cosyra* emerging and those of

Figure 6. Number of *Bactrocera invadens* and *Ceratitits cosyra* counted by kg of fruits and by mango variety in a modern-type orchard in Sindia (Thiès Plateau, Senegal).



B. invadens ($P = 0.942$). However, *B. invadens* emergence numbers are significantly more substantial than for *C. cosyra* in the traditional-type orchard in Pout ($P < 0.003$). On the other hand, where *C. cosyra* is implicated in mango infestations, the emergence of *C. cosyra* is significantly greater in Sindia than in Pout ($P < 0.034$). Looking at the varieties, *C. cosyra* emergence is significantly greater with Valencia and Haden compared with Divine, Early Gold, Boucodiékhhal, Irwin, Sensation, Pêche, Colombo, Amélie, David Haden, Sanguine, Kent, Keitt, Greffal, Dieg bou gatt and Heidy. This is not the case for the infestations linked to *B. invadens*, which are of greater significance in the traditional orchard in Pout than in the modern-type one in Sindia ($P < 0.0001$). However, there is no significant difference between mango varieties in these orchards in terms of the emergence of *B. invadens*.

3.3.4. Influence of fruit condition on the variability of Tephritidae emergence from citrus and mango

The physiological and morphological parameters, such as fruit condition, size and color, of commercial host fruits such as citrus and mango trees were studied.

3.3.4.1. Citrus

Studies on the impact of fruit condition on Tephritidae emergence from citrus fruits showed that, among the citrus species, the genus *Fortunella* was the most infested by *B. invadens* when compared with members of the genus *Citrus* ($P < 0.0001$), i.e., *C. aurantium*, *C. aurantifolia*, *C. clementina*, *C. deliciosa*, *C. reticulata*, *C. limon*, *C. paradisi* and *C. sinensis* (table IV). Infestation was greater for *F. japonica* than for *F. margarita*. On the other hand, the limequat drawn from crossing *Fortunella* sp. × *Citrus* sp. was significantly less infested than *F. japonica* ($P < 0.009$) but there is no significant difference between this hybrid and *F. margarita* ($P = 0.323$).

As well as species, the number of Tephritidae emerging from collected citrus fruits varied according to cultivar and fruit condition (table IV). With the exception of *Citrus limon*, where there were more Tephritidae from rotting fruit, newly ripe fruits of the various citrus produced the highest emergence. The lowest emergence was from aborted fruits. For *Citrus aurantifolia*, Tahiti lime was the most infested in contrast to either Yuma lime or spineless limes, which produced no fruit flies. Among the *C. paradisi* grapefruits, the cultivar Orobianco was the most infested by

Table IV.

Impact of the development stage of the fruit on the Tephritidae emergence in citrus fruits in orchards of the Niayes and Thiès Plateau zones, in Senegal.

Citrus	Tephritidae (emerged flies) per kg		<i>Bactrocera invadens</i>	<i>Ceratitis cosyra</i>	<i>Ceratitis capitata</i>	Quantity of fruits sampled (kg)
	General means	Partial means per development stage				
<i>Fortunella japonica</i>	240.00 a	–	239.6	0	0.4	3.032
ripe	–	240.0	239.6	0	0.4	3.032
<i>Fortunella margarita</i>	115.50 ab	–	95.8	0	19.7	8.159
ripe	–	115.5	95.8	0	19.7	8.159
Limequat	86.5 b	–	86.5	0	0	3.959
ripe	–	86.5	86.5	0	0	3.959
<i>Citrus aurantium</i>	61.40 bc	–	61.4	0	0	6.733
ripe	–	76.8	76.8	0	0	5.533
senescent	–	0	0	0	0	1.200
<i>Citrus deliciosa</i>	26.20 c	–	26.2	0	0	14.326
aborted	–	0	0	0	0	0.556
ripe	–	29.4	29.4	0	0	13.033
senescent	–	0	0	0	0	0.737
Tangélo	16.50 c	–	16.5	0	0	2.591
ripe	–	16.5	16.5	0	0	2.591
<i>Citrus clementina</i>	15.30 c	–	14.6	0.7	0	11.781
aborted	–	0	0	0	0	0.171
fissured	–	0	0	0	0	0.275
ripe	–	18.9	18.1	0.9	0	9.992
senescent	–	0	0	0	0	1.343
<i>Citrus aurantifolia</i>	15.00 c	–	15.0	0	0	34.431
aborted	–	0	0	0	0	0.377
Yuma lime	–	0	0	0	0	0.377
ripe	–	17.3	17.3	0	0	31.202
IAC lime	–	2.8	2.8	0	0	4.741
Mexican lime	–	2.6	2.6	0	0	8.681
Spineless lime	–	0	0	0	0	0.736
Tahiti lime	–	37.8	37.8	0	0	16.461
Yuma lime	–	0	0	0	0	0.583
senescent	–	2	2	0	0	2.852
IAC lime	–	0	0	0	0	1.904
Tahiti lime	–	6	6	0	0	0.948
<i>Citrus sinensis</i>	13.80 c	–	13.8	0	0	11.785
aborted	–	4.3	4.3	0	0	1.677
Hamelin	–	13	13	0	0	0.451
Japanese orange	–	0	0	0	0	1.226
ripe	–	17	17	0	0	10.108
Hamelin	–	20.2	20.2	0	0	6.256
Japanese orange	–	13	13	0	0	3.852

Table IV. (continued)

Impact of the development stage of the fruit on the Tephritidae emergence in citrus fruits in orchards of the Niayes and Thiès Plateau zones, in Senegal.

Citrus	Tephritidae (emerged flies) per kg		<i>Bactrocera invadens</i>	<i>Ceratitis cosyra</i>	<i>Ceratitis capitata</i>	Quantity of fruits sampled (kg)
	General means	Partial means per development stage				
<i>Citrus paradisi</i>	8.00 c	–	8.0	0	0.04	65.469
aborted	–	0.10	0.1	0	0	9.343
Marsh	–	0	0	0	0	0.230
Red blush	–	0.25	0.25	0	0	5.528
Shambar	–	0	0	0	0	3.585
ripe	–	9.3	9.3	0	0.04	55.788
Marsh	–	5	5	0	0	10.590
Orobianco	–	14.2	14.2	0	0	15.582
Red blush	–	8.1	7.9	0	0.2	7.807
Shambar	–	8.6	8.6	0	0	21.809
senescent	–	0	0	0	0	0.338
Red blush	–	0	0	0	0	0.338
<i>Citrus limon</i> (Eureka)	2.20 c	–	2.2	0	0	13.373
ripe	–	1.7	1.7	0	0	9.704
senescent	–	3.3	3.3	0	0	3.669
Tangor	2.00 c	–	2	0	0	0.488
ripe	–	2	2	0	0	0.488
<i>Citrus maxima</i>	0.00 c	–	0	0	0	2.029
ripe	–	0	0	0	0	2.029

The letters a, b and c represent groups that are significantly different.

B. invadens. *Ceratitis capitata* was most commonly found among the *C. paradisi* grapefruits and kumquats, where *F. margarita* was more infested than *F. japonica* and *C. paradisi* ($P < 0.001$), contrary to what is observed with *B. invadens*. *Ceratitis cosyra* was found on *C. clementina* in particular. Fruit size had a significant effect on citrus infestations, e.g., fruits of *C. deliciosa* with a diameter between 5 cm and 10 cm demonstrated significantly greater levels of emergence than fruits with a diameter less than 5 cm ($P < 0.028$).

3.3.4.2. Mango

For *Mangifera indica* orchards, fruit fly emergence varies according to the variety

(table V). Across all the mangoes collected from 19 orchards, the varieties Séwé, Davis Haden, Kent, Keitt, Dieg bou gatt, Valencia, Boucodiékhhal, Pêche, Sanguine, Colombo and Haden provided more than 20 fruit flies per kg of mangoes. The average kg of mangoes produced 25 specimens of *B. invadens* against two of *C. cosyra*. However, fruit condition at the moment of sampling influenced the numbers emerging from each variety. Mangoes with tunneling or other wounds had significantly greater infestation levels than aborted mangoes, ripe mangoes and those with advanced spoiling ($P < 0.029$). However, fruit condition on its own produced no significant differences among the greatest value infestations associated with *C. cosyra* in either mature or

Table V.

Impact of the stage of development of the fruit on the Tephritidae emergence in mango varieties in orchards of the Niayes and Thiès plateau zones, in Senegal.

Varieties and condition of fruit	Number of flies per kg fruits			Quantity of fruits (kg)
	<i>Bactrocera invadens</i>	<i>Ceratitis cosyra</i>	Total flies	
<i>Mangifera indica</i>	25.79	2.66	28.44	374.58
Séwé	76.92	0.38	77.31	7.59
aborted	166.00	0.00	166.00	2.24
ripe	37.33	0.56	37.89	5.34
David Haden	56.20	1.20	57.40	10.57
aborted	0.00	0.00	0.00	1.10
ripe	62.44	1.33	63.78	9.47
Kent	34.64	0.66	35.30	75.52
aborted	28.89	0.95	29.84	45.41
fissured	43.00	0.00	43.00	2.14
ripe	45.90	0.10	46.00	27.98
Keitt	34.08	0.73	34.82	71.33
aborted	20.90	0.85	21.74	38.84
fissured	159.25	0.00	159.25	5.45
ripe	34.88	0.65	35.53	27.04
Dieg bou gatt	34.63	0.00	34.63	7.16
aborted	56.50	0.00	56.50	1.35
ripe	27.33	0.00	27.33	5.81
Valencia	20.06	12.59	32.65	14.24
aborted	27.50	18.40	45.90	7.11
ripe	9.43	4.29	13.71	7.14
Boucодиékhal	24.69	3.15	27.83	69.17
aborted	26.50	4.62	31.12	41.73
immature	0.00	0.00	0.00	2.44
ripe	25.69	0.81	26.50	21.33
senescent	10.50	0.00	10.50	3.67
Pêche	23.30	2.80	26.10	7.08
aborted	7.33	1.00	8.33	1.98
ripe	30.14	3.57	33.71	5.10
Sanguine	23.60	1.40	25.00	3.78
aborted	3.00	0.00	3.00	0.65
ripe	28.75	1.75	30.50	3.13
Colombo	19.23	3.69	22.92	13.15
aborted	20.75	5.13	25.88	5.47
ripe	16.80	1.40	18.20	7.69
Haden	6.85	13.92	20.77	15.32
aborted	0.00	23.67	23.67	1.44
ripe	8.90	11.00	19.90	13.88
Palmer	13.75	5.00	18.75	4.41
aborted	17.50	0.00	17.50	2.37
ripe	15.20	0.00	15.20	8.14

Table V. (continued)

Impact of the stage of development of the fruit on the Tephritidae emergence in mango varieties in orchards of the Niayes and Thiès Plateau zones, in Senegal.

Varieties and condition of fruit	Number of flies per kg fruits			Quantity of fruits (kg)
	<i>Bactrocera invadens</i>	<i>Ceratitis cosyra</i>	Total flies	
Sensation	9.00	4.00	13.00	5.66
aborted	5.67	0.00	5.67	2.00
ripe	12.33	8.00	20.33	3.66
Birane Diop	1.00	11.33	12.33	1.23
aborted	0.00	0.00	0.00	0.20
ripe	1.50	17.00	18.50	1.04
Amélie	7.38	1.29	8.67	27.84
aborted	9.11	2.44	11.56	6.41
ripe	6.08	0.42	6.50	21.44
Early gold	2.30	4.20	6.50	7.65
aborted	0.33	1.67	2.00	2.93
ripe	5.25	8.00	13.25	4.72
Koy khar	6.00	0.00	6.00	2.06
aborted	2.50	0.00	2.50	0.41
ripe	9.50	0.00	9.50	1.65
Heidy	3.67	0.00	3.67	6.55
ripe	3.67	0.00	3.67	6.55
Divine	0.33	3.00	3.33	5.30
aborted	0.50	0.00	0.50	2.04
ripe	0.25	4.50	4.75	3.26
Allongée	3.00	0.00	3.00	2.32
aborted	3.00	0.00	3.00	2.32
Irwin	0.00	2.50	2.50	4.99
aborted	0.00	7.00	7.00	1.47
ripe	0.00	0.25	0.25	3.52
Ruby	0.00	0.00	0.00	2.20
aborted	0.00	0.00	0.00	0.72
ripe	0.00	0.00	0.00	1.48
Zill	0.00	0.00	0.00	0.70
aborted	0.00	0.00	0.00	0.70

aborted mangoes. The varieties Birane Diop, Valencia and Haden are significantly more infested by *C. cosyra* ($P < 0.034$), while *B. invadens* demonstrates no differences in infestation among varieties.

Mango infestations linked to *C. cosyra*, unlike *B. invadens*, showed significant differences based on skin color. *Cerati-*

tis cosyra infested more greenish-yellow mangoes and yellow and green (aborted) mangoes than it did those that were red, reddish-yellow or reddish-green ($P < 0.032$). The extent of *C. cosyra* emergence increased as a function of fruit dimension but no significant differences were found between the different size classifications:

0–5 cm, 5–10 cm, 10–15 cm and 15–20 cm. Furthermore, infestations caused by *B. invadens* were greater on smaller mangoes (0–5 cm) than for the largest fruits ($P < 0.039$). While the average emergence values for *C. cosyra* were greater for fruits collected from the ground, those for *B. invadens* came from tree-harvested fruits. Notwithstanding these observations, there are no significant differences in emergence of these two species, irrespective of whether the fruits are sampled from the tree or from the ground ($P > 0.05$). Over the two seasonal flowering periods noted for the mango trees, the emergence of *B. invadens* was greater for the mangoes developing from the second flowering period ($P < 0.017$) unlike *C. cosyra*, for which emergence was more associated with the earlier flowering.

4. Discussion

The cultivated and self-seeded fruit plants found in the orchards were characterized by overlapping production periods. Therefore fruits, most of which are hosts for Tephritidae, were present at all times throughout the study. Tephritidae populations peaked during the fructification periods of certain self-seeded plants, mangoes and citrus. The naturally occurring fruit trees in and around the orchards play an important role in the Tephritidae population dynamic and in their species diversity. Moreover, there is an important role played in influencing species infestation and species strength by spiny woody perennials such as *Ziziphus mauritiana* and *Capparis tomentosa* used in the protective hedges for traditional orchards, both of them reaching maturation before mangoes. The jujube hosted *Bactrocera invadens* and *Carpomyia* sp., while the caper provided a refuge for *Capparimya bipustulata*, *Ceratitis capitata*, *C. cosyra* and *Bactrocera invadens*. The climber *Kedrostis birtella*, which grew on the other plants, hosted *Bactrocera invadens* as well as *Dacus ciliatus*, *D. vertebratus* and *B. cucurbitae*. These hosts were active outside the period for mangoes and the use of these prickly plants in the

hedges of traditional orchards needs to be reconsidered in terms of managing *B. invadens* populations.

Meanwhile, research on parasitoids for biological control should focus on certain plants such as the caper because of their widespread presence. The importance of these alternative hosts in the traditional orchards means they were more infested than modern orchards. In effect, the traditional orchards were characterized by the diversity of fruit species and the complex of both local and improved varieties, whether late or early, that resulted from limited tending of stands and limited pesticide use. The resulting succession of flowering periods for the different fruit trees and plant hosts prolonged availability of both food and oviposition sites and helped maintain high population levels. Furthermore, the lack of pruning at the end of the season and the irregularity of collecting the highly susceptible aborted mangoes turned the traditional orchards into favorable havens of development for Tephritidae. A number of early and maincrop mangoes reached maturity in June and July. These included the varieties Séwé, Koy khar, Birane Diop, Greffal, Dieg bou gatt, David, Valencia, Colombo, Haden, Pêche, Amélie, Sensation, Early Gold, Irwin, Zill and Ruby. The late varieties took over from the end of July (David Haden, Palmer, Boucodiékhhal, Divine, Heidy, Kent and Keitt). Therefore, these orchards reached high levels of emergence much earlier than in the so-called modern orchards. At the end of the mango season, these heavy populations of Tephritidae dropped quickly because of a scarcity of food and laying sites.

The game plan for *B. invadens* is characterized by rapid population increase and massive colonization of new habitat, followed by a rapid decline in numbers when conditions turn against it [7]. Among all the flies recorded here *B. invadens* had the largest range, corroborating reports from Mwatawala *et al.* [7] and Drew *et al.* [15]. Its laying capacity (794.6 eggs), its high net fertility (608.1 eggs), average deposition of 18.2 eggs per day, its ability to produce several broods each year and short breeding time [8] contributed to its abundance. Its polyphagous nature was proven by its

infestation of 34 species of fruit tree in the Niayes and Thiès Plateau areas. *Ceratitidis cosyra* behaved in the same way, but, on the other hand, *C. breinii*, *C. punctata* and *Capparimyia bipustulata* were more oligophagous and were retrieved from single fruit tree species: *Cordyla pinnata*, *Acbras sapota* and *Capparis tomentosa*, respectively. In Cameroon, *B. invadens* was found in guava [16]. Among citrus trees, *Fortunella japonica* and *F. margarita* (limequat) were significantly more infested by *B. invadens* ($P < 0.0001$). The hybrid *Fortunella* × *Citrus aurantifolia* harbored 86 specimens per kg but was not significantly different from other species of *Citrus*. One explanation for the extent of the infestations on *Fortunella* might be its thinner skin than the other citrus cultivars studied.

The low infestation levels of *B. invadens* on certain citrus trees confirmed work carried out by Mwatawala et al. [17] in Tanzania and by Vayssières et al. [18] in Benin; yet *B. invadens* is predominant over *C. capitata* and *C. cosyra* on citrus trees. Other than mango, *C. cosyra* attacked cultivated fruits (*Annona senegalensis*, *Citrus aurantium*, *Persea americana*, *Psidium guajava*, [5, 19–21], *Citrus reticulata*, *C. sinensis* and *Butyrospermum parkii*), and wild fruits (*Sarcocephalus latifolius* and *Landolphia senegalensis*) [22]. Before the arrival of *Bactrocera invadens*, *Ceratitidis cosyra* predominated on *C. quinarina* (Bezzi) and *C. silvestrii* Bezzi, early species in Mali's mango season [23, 24]. Among the range of varieties found in the study zone, *Ceratitidis cosyra* was the second most significant Tephritidae pest after *B. invadens*. However, large numbers of *C. cosyra* – up to 50 larvae per fruit [24] – emerged from *Cordyla pinnata* berries in this study, dominating those of *B. invadens*. In capers and sapodilla plums, *Bactrocera invadens* was dominated by, respectively, *Capparimyia bipustulata* and *Ceratitidis punctata*. However, *Carpomyia* sp. attacking cultivated [25] and wild [26] jujube plants competed with *B. invadens*, which developed greater numbers of larvae in Gola jujube trees. *Ceratitidis capitata* is a major pest of Solanaceae [27] but also damages citrus trees [28], guava and

other wild and cultivated fruit trees [5, 20, 22].

Parameters such as fruit condition, color, size, flowering period, point of collection and variety had a strong influence on *B. invadens* and *C. cosyra* emergence in mangoes. There were no varietal differences evident in *B. invadens* infestations but *C. cosyra* was very significant in early varieties, particularly for green aborted mangoes and yellow ripe mangoes. *Ceratitidis cosyra* is a major pest in fruits set in the first flowering period, which confirms its earliness in relation to the mango season [22, 28]. On the other hand, *Bactrocera invadens*, which accounts for 58% of the total flies from yellow mangoes, was found on the full gamut of mango colors without significant difference in numbers. Females of *Ceratitidis* species are attracted to the fruits by smell and color, particularly yellow, orange and red [28]. The Tephritidae emerged more frequently from mangoes retrieved from the ground than from those picked from trees. It seemed some Tephritidae preferred to lay eggs on shaded parts of fruits rather than on sunny surfaces [29].

This observation reinforced the importance of targeted control measures for fruit flies in orchards [30]. In Keitt, mangoes with cracks were significantly more infested by *B. invadens* because certain species of *Bactrocera* lay in the recent oviposition holes of other females or in fruit wounds [31]. The results showed that *B. invadens* infested even small fruits [28], but the greater the size of the fruit, the greater the emergence of *C. cosyra*. Moreover, shape and color became an olfactory stimulus for visiting fruits, making a hole and ovipositing [32]. *Bactrocera invadens* was more significant than *Ceratitidis cosyra* in brown (chestnut) senescing fruits fallen to the ground. Certain Tephritidae maintain a symbiotic nutritional relationship with bacteria that supply them with amino acids and other growth factors in return for help with protection and dispersion of the bacteria [33]. The data on varietal influence of mango condition, color, size and collecting point on the emergence of *B. invadens* and *C. cosyra* revealed oviposition preferences. It seems that *B. invadens* was an invasive, polyphagous

and colonizing species which competed with autochthonous Tephritidae. However, the dynamics of the two species do not clearly show the exclusion processes [7]. While *B. invadens* showed itself to be opportunistic and invasive, *Ceratitidis cosyra* quickly peaked in conjunction with the seasonal stage of the mango, making *C. cosyra* a major pest in early cultivars [34].

5. Conclusion

The present study showed that the dynamics of the emergence of Tephritidae in orchards increased following the ripening periods of the main host plants (capers, mangoes, citrus and cucurbitaceous plants). *Bactrocera invadens* infests a number of fruit tree species in the Niayes and Thiès Plateau zones, including 13 citrus species, 24 varieties of mango and 18 other fruit species. These species are members of the Annonaceae, Apocynaceae, Capparidaceae, Caricaceae, Ceasalpiniaceae, Cucurbitaceae, Myrtaceae, Palmaceae Rhamnaceae, Rutaceae and Sapotaceae families. The diversity of fruit trees (cultivated and self-seeded), the lack of pest control and weak orchard care help sustain the Tephritidae outside the mango season. Once mango development gets underway, *Bactrocera invadens* and *Ceratitidis cosyra* establish themselves in fruits dropped before maturation. The extent of their emergence varies from one orchard to another depending on the type of orchard, the species and varietal composition. The traditional type of orchard is more infested than the modern type. The physiological state of the fruit plays a far from negligible role in Tephritidae infestations. This fruit parameter must be taken into account in all comparative trials (variety comparisons, agronomic trials and inter-site comparisons).

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Estacionalidad y gama de las moscas de las frutas (Tephritidae, dípteros) identificadas en las plantas huésped de los vergeles de Niayes y de la meseta de Thies (Senegal).

Resumen – Introducción. La producción de fruta de Senegal se estima en 150.000 t, de las cuales 60.000 t son mangos. Los cítricos representan el 24% de esta producción y se sitúan en segunda posición, después del mango, el cual representa el 60% de la producción frutera, la cual es muy importante en las Niayes. Con la llegada de *Bactrocera invadens* a Senegal aumentaron las pérdidas de producción de mangos. Las poblaciones de la plaga son considerables en periodos de maduración de los frutos, pero las informaciones referentes a sus huéspedes secundarios son escasas. **Material y métodos.** Se cosecharon de modo habitual los frutos de las especies fruteras cultivadas y espontáneas, de abril a diciembre de 2008, en 19 vergeles y en su alrededor, en once localidades de la zona de las Niayes y de la meseta de Thies (Senegal). Se hizo el seguimiento de estos frutos para determinar las especies de las moscas hospedadas, y hacer así un repertorio de sus plantas huésped. En el caso del mango, el estudio pretendió mostrar la influencia de parámetros, tales como: la variedad, el tamaño del fruto, el color, la ola de floración o el estado fisiológico en las infestaciones por *B. invadens* y *Ceratitis cosyra*. En función de su composición y de su modo de conducta, se clasificaron los vergeles en dos tipos: tradicional (numerosas variedades de mangos y numerosas especies de frutas cultivadas a la vez en el seno de una misma parcela) o moderno (parcelas monovarietales de mangos). **Resultados y discusión.** En total, se sacaron muestras tanto en el suelo como en el árbol de 663,2 kg de frutos, correspondientes a 24 variedades de mangos, 13 especies de cítricos, de las cuales 5 variedades de limero, 2 variedades de naranjos y 4 variedades de pomelos, así como otras especies fruteras cultivadas o espontáneas. Los vergeles de tipo tradicional se infestaron más que los vergeles de tipo moderno. Entre los Tephritidae pertenecientes a los frutos cosechados, la especie *B. invadens* fue significativamente dominante en *Ceratitis cosyra*, *C. capitata*, *C. punctata*, *C. bremii*, *Bactrocera cucurbitae*, *Capparimyia bipustulata*, *Carpomyia* sp. y *Dacus* sp. La especie *B. invadens* se encontró en 24 variedades de *Mangifera indica*, 19 cultivares de cítricos, y en otras especies fruteras cultivadas y espontáneas. Algunas plantas huésped mantuvieron los niveles de poblaciones de *B. invadens* antes del periodo de maduración del mango. El mango se infestó principalmente por *B. invadens* y *C. cosyra*. La especie *C. cosyra* es significativamente importante en los frutos correspondientes a las primeras olas de floración y, sobre todo, en las variedades precoces, mientras que *B. invadens* está presente en todas las variedades, independientemente del estado del fruto, su color, la ola de floración y el lugar de cosecha. **Conclusión.** Dada la diversidad de las plantas huésped y de las variedades, los vergeles tradicionales fueron más infestados que los vergeles modernos. El control de esta plaga precisa definir un sistema de lucha integrada basada en un estudio de base de las moscas de las frutas presentes, de los parasitoides existentes y de sus huéspedes.

Senegal / frutales / plantas huéspedes / *Mangifera indica* / *Citrus* / Tephritidae / *Bactrocera invadens* / *Ceratitis cosyra* / huerto frutal / muestra