Original article

Seasonal abundance of fruit flies (*Diptera*: *Tephritidae*) on mango orchard and its relation with biotic and abiotic factors in Manica Province, Mozambique

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Summary

Introduction – **Mango (*Mangifera indica* L.) is a fruit species with high potential for reduction of hunger and poverty in Mozambique. However, the production of this crop is currently threatened by various fruit fly species, including *Bactrocera dorsalis* (Hendel) and *Ceratitis cosyra* (Walker). Their occurrence in Mozambique needed to be assessed.** *Materials and methods* – **Fruit flies (*B. dorsalis* and *C. cosyra*) were monitored over two consecutive mango cropping seasons from September 2014 to August 2016 on 10 ha of a commercial mango orchard in Vandúzi district, Mozambique. Trapping activities were conducted using Chempac Bucket traps baited with food attractant (torula yeast). Temperature data and host phenology data were recorded at the orchard, while rainfall data were obtained from a meteorological station located 10 km away.** *Results and discussion* – **Fruit fly populations were present in the orchard over the entire trapping period (for *B. dorsalis*); or absent at some periods during vegetative stages of the mango (for *C. cosyra*). For both cropping seasons, the population of *B. dorsalis* peaked in January. For *C. cosyra*, the peak was observed in January of the first cropping season, while it was observed in November of the second season. The population of both species varied between the seasons, but in general *B. dorsalis* was more abundant than *C. cosyra* (average relative abundance index RAI = 0.814). The *B. dorsalis* population density had a positive relationship with minimum temperatures and mango phenology stages and a negative relationship with average temperatures, while the population of *C. cosyra* had a positive relationship with minimum temperatures.** *Conclusion* – **The populations of *B. dorsalis* and *C. cosyra* in Mozambique fluctuated throughout the cropping year, *B. dorsalis* was more abundant than *C. cosyra* with some periods of exclusive presence. This fluctuation seems well-related to biotic and abiotic factors.**

Keywords
Mozambique, mango, *Mangifera indica*, *Bactrocera dorsalis*, *Ceratitis cosyra*, population dynamics

Significance of this study

What is already known on this subject?

- *Bactrocera dorsalis* is an invasive species of fruit fly in Africa and the most important, attacking a large number of hosts including mango.
- *Ceratitis cosyra* is a native species with mango as one of the most important hosts.
- After invasion, *B. dorsalis* is displacing *C. cosyra* in many East and West African countries.

What are the new findings?

- *Bactrocera dorsalis* still coexists with *Ceratitis cosyra* in Mozambique after its invasion, but more abundant than the native species.
- Both populations fluctuate throughout the year, related to biotic and abiotic factors.

What is the expected impact on horticulture?

- Understanding the relationship between population fluctuations and biotic and abiotic factors will allow anticipating the build-up of pest populations; and
- It can assist the growers in predicting population growth and taking precautionary measures.

Résumé

Abondance saisonnière des mouches des fruits (*Diptera*: *Tephritidae*) et relations avec les facteurs biotiques et abiotiques en verger de manguiers dans la province de Manica au Mozambique.

Introduction – **Le manguier (*Mangifera indica* L.) est une espèce fruitière ayant un fort potentiel de réduction de la faim et de la pauvreté au Mozambique. Cependant, la production de mangues est actuellement menacée par diverses espèces de mouches des fruits, dont *Bactrocera dorsalis* (Hendel) et *Ceratitis cosyra* (Walker). Leur apparition au Mozambique doit être évaluée.** *Matériels et méthodes* – **Les populations de mouches des fruits (*B. dorsalis* et *C. cosyra*) ont été suivies pendant deux saisons de culture consécutives**

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de septembre 2014 à août 2016, dans un verger de 10 ha de manguiers commerciaux dans le district Vandúzi, au Mozambique. Les activités de piégeage ont été menées à l'aide de pièges Chempac Bucket avec un attractif alimentaire (levure de torula). Les données de températures et les données phénologiques de l'hôte ont été enregistrées au verger, tandis que les données de précipitations ont été obtenues à partir d'une station météorologique située à 10 km. *Résultats et discussion* – **Les mouches des fruits étaient présentes dans le verger pendant toute la période de piégeage (cas de *B. dorsalis*); ou absentes à certaines périodes pendant les étapes végétatives du manguier (cas de *C. cosyra*). Sur les deux saisons de culture, la population de *B. dorsalis* a atteint un sommet en janvier. Pour *C. cosyra*, le pic de population a été observé en janvier de la première saison de culture, alors qu'il a été observé en novembre de la deuxième saison. Les populations de chaque espèce ont présenté des variations selon les saisons, mais en général, *B. dorsalis* a été plus abondante que *C. cosyra* (indice d'abondance relative moyenne RAI = 0,814). La densité de population de *B. dorsalis* est en corrélation positive avec les stades phénologiques de la mangue et la température minimale, et en corrélation négative avec la température moyenne, tandis que la population de *C. cosyra* est en corrélation positive avec la température minimale au verger.** *Conclusion* – **Les populations de *B. dorsalis* et de *C. cosyra* au Mozambique ont fluctué tout au long de l'année de culture, *B. dorsalis* était plus abondante que *C. cosyra* avec quelques périodes de présence exclusive. Cette fluctuation semble liée à des facteurs biotiques et abiotiques.**

Mots-clés
Mozambique, manguier, *Mangifera indica*, *Bactrocera dorsalis*, *Ceratitis cosyra*, dynamique des populations

Introduction

Horticulture is one of the most important agricultural subsectors in Africa, providing income, creating employment opportunities, and enhancing food and nutritional security (Ekesi *et al.*, 2016; Vayssières *et al.*, 2008). In Mozambique, fruit trade generated more than \$ 20 M year^{-1} in Manica and Maputo provinces (Cugala, 2011). Mango (*Mangifera indica* L.) is considered the second fruit crop with highest production in the country, after banana (*Musa* spp.), with an average production of about 35.000 t year^{-1} (FAOSTAT, 2015). The crop is produced across various regions around the country by smallholder farmers on small family plots for subsistence. Manica province is the only region where mango is produced in large commercial plantations for export mainly for South Africa (Bota, 2016). Mango exports generated to the country more than \$ 758 thousand from 2006 to 2009 (José *et al.*, 2013).

The occurrence of fruit flies, including *Bactrocera dorsalis* Hendel and *Ceratitis cosyra* Walker, is the most important factor hampering the production of mango in Africa in general and Mozambique in particular (Ekesi *et al.*, 2009; Mwatawala *et al.*, 2006; Cugala, 2011). *Ceratitis cosyra* is an African native species and, prior to the arrival of *B. dorsalis,* it was considered as the most important pest on mango in sub-Saharan Africa (Virgilio *et al.*, 2017). *Bactrocera dorsalis* is an invasive species, native from Sri Lanka, reported for the first time in Africa in 2003, and is now largely distributed over the entire continent, infesting several fruit species including mango (Goergen *et al.*, 2011). Studies conducted in Kenya and Tanzania indicated that after the invasion of *B. dorsalis* the populations of *C. cosyra* have been largely displaced by the former (Ekesi *et al.*, 2009; Mwatawala *et al.*, 2006). In Mozambique, *B. dorsalis* was first detected in 2007 in the northern region (Correia *et al.*, 2008), and now the pest is established all over the country. Direct losses on mango due to native fruit flies are around 40% in Africa, however, with the invasion of *B. dorsalis* the impact increased to more than 50% (Vayssières *et al.*, 2014). Indirect losses attributed to quarantine restrictions are also high. For example, following the *B. dorsalis* invasion in 2003, Kenya lost its entire avocado (*Persea americana*) export market in South Africa, resulting in revenue losses of \$ 1.9 million in 2007 (Ekesi *et al.*, 2016). The temporary closure of the South African market for three weeks in October 2008 resulted in the loss of about \$ 2.5 M in Mozambique (Cugala, 2011).

Several studies were conducted to assess the seasonal fluctuation of fruit flies in mango orchards in Uganda (Mayamba *et al.*, 2014), Mexico (Aluja *et al.*, 1996), India (Sarada *et al.*, 2001), Malaysia (Tans and Serit, 1994), China (Chen *et al.*, 2006), Tanzania (Mwatawala *et al.*, 2006), Benin, Burkina Faso, Ivory Coast, Ghana, Guinea, Mali, Senegal and Togo (Vayssières *et al.*, 2014). In general, adult population shows fluctuations throughout the year, however, the factors behind the fly seasonality are not fully understood since they may vary from one to another region. In Mozambique, a study on *B. dorsalis* dynamics were conducted but a pheromone lure methyl eugenol was used (Majacunene, 2014), not allowing to describe the changes at farm level since it can attract flies from more than 2 km distance from the orchard. On this study we provide, for the first time in Mozambique, data on fluctuation of both fruit flies species (*B. dorsalis* and *C. cosyra*) on a mango orchard in a long-term monitoring (24 months, covering two mango seasons), and its relation with biotic and abiotic factors at a farm level. Due to the importance of Manica Province as a mango producing area and also to the need for knowledge on the population dynamics of fruit flies as a prerequisite for development of an appropriate control program, the present study was conducted along the following objectives: to assess (i) the seasonal fluctuation of *B. dorsalis* and *C. cosyra* over two consecutive mango seasons in one of the main mango production areas, (ii) the relative abundance index between the two species, and (iii) the relation of the seasonal fluctuation of the flies with biotic and abiotic factors.

Materials and methods

Study sites

Data were collected in a 10-ha commercial mango (*Mangifera indica* L.) orchard in Mozambique, Manica Province, Vandúzi District (18°94'S latitude, 33°18'E longitude, 700 m) (Figure 1). Two varieties of mango were produced in the orchard: 'Tommy Atkins' (occupying more than 80%) and 'Keitt' (less than 20%). The orchard is surrounded by permanent pastures, maize (*Zea mays* L.) fields, and scattered trees of wild mango variety and guava (*Psidium guajava* L.) (Figure 2). Mango was the only crop produced in the orchard and the main cultural activities were pruning after harvest, and mechanical weed control.

The study area has a tropical climate, with an annual average temperature of 21.2 °C, and rainfall from 1,000 to 1,020 mm. The rainy season starts around October-November and ends in February-March. The soils are mainly red oxides, deep and well drained, with a rolling topography (MAE, 2005).

Trapping

Trapping was done according to IAEA guidelines (IAEA, 2013) with modifications. Twenty-six plots were demarcated in the orchard. Each plot was composed of six labeled trees. Two replicate traps were placed within each plot on different trees (Figure 2). In total 52 Chempac Bucket traps (Insect Science©) baited with torula yeast (Insect Science©)

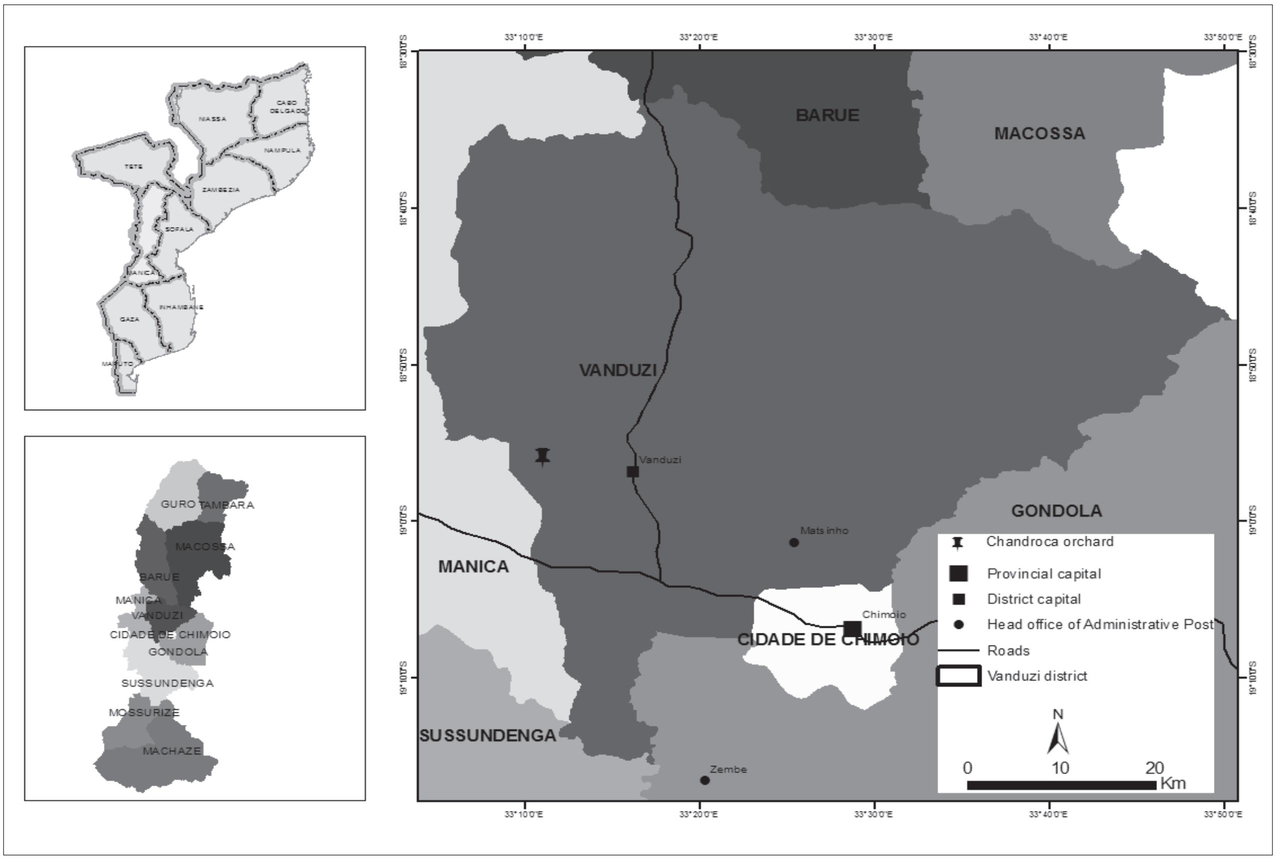

FIGURE 1. Geographic location of the Vandúzi District, Mozambique.

FIGURE 2. Physical location of the plots in the studied mango orchard (Source: Google Earth, 2016).

(250 mL per trap) were placed in the orchard. Torula yeast was diluted in water at the proportion of 3 tablets L^{-1} water. Chempac Bucket traps is a modification of McPhail trap and it is recommended for liquid attractants such as torula yeast (Manrakhan, 2017, Uchida *et al.*, 1996). The torula solution was replaced weekly, after cleaning the traps. All used torula yeast was removed from the orchard to avoid contamination. The position of each trap was determined with a GPS Garmin *etrex 30*.

The data were collected over two years, with weekly trapping during mango season (September 2014 till February 2015 and August 2015 till February 2016) and monthly trapping during off-mango season (March 2015 till July 2015 and March 2016 till August 2016) due to the low number of fruit fly catches.

Species identification

All fruit flies captured in the traps were preserved in 70% ethanol, taken to the National Fruit Fly Laboratory of Chimoio and identified to genus and species level, using the electronic key developed by Virgilio *et al.* (2014). After identification to species level, only *B. dorsalis* and *C. cosyra* specimens were considered for further study because of their significance and importance as mango pests (Ekesi *et al.*, 2009; Vayssières et *al.*, 2015).

Biotic and abiotic factors

Host phenology was recorded during the entire period covered by the study, recognizing four stages as defined by Vayssières *et al.* (2015): (1) Vegetative growth; (2) Flowering; (3) Fruit formation and development; and (4) Maturity stage. The phenology of alternative hosts like guava and local varieties of mango were also recorded. Temperature data were collected using 26 data loggers or thermochron (iButtons Dalsemi®) placed at each plot within the orchard. The data logger resolution used was 0.50 °C. Rainfall data were obtained from Vandúzi Company meteorological station located 10 km from the orchard.

Data analysis

For each species, flies captures were expressed as FTD (average number of adult flies $trap^{-1}$ day^{-1}) calculated by plot and trapping date (IAEA, 2013). One-way Analysis of Variance (ANOVA) and *a posteriori* SNK tests were used to verify the effects of host phenology (fixed factor, 4 levels) on the target species density, which was [log (x+1)] transformed before submitted to ANOVA.

Non-parametric Mann Whitney test was used to compare the abundances between the two species and mango seasons. Log-linear regression with Poisson distribution was used to evaluate relationships between abundance of the flies and covariates including mango phenology, temperatures (minimum, maximum and average) and rainfall (Nene *et al.*, 2016). Relative Abundance Index (RAI) was used to describe relationships between the abundance of *B. dorsalis* and *C. cosyra* in the orchard over time calculated for each trapping date, and plotted for each phenology stage of mango according to the formula proposed by Segura *et al.* (2006):

$$RAIxy = \frac{Bd}{(Bd + Cc)}$$

where *Bd* is the number of adult of *B. dorsalis* and *Cc* the number of adult *C. cosyra* captured on the trap *x* and trapping date *y*. RAI ranges from 0 to 1 and grouped in five categories: exclusive presence of *B. dorsalis* (RAI = 1); exclusive presence of *C. cosyra* (RAI = 0); both species present but *B. dorsalis* in high abundance ($1 < RAI < 0.66$), intermediate cases ($0.66 < RAI < 0.33$) and both species present but *C. cosyra* in high abundance ($0.33 < RAI < 0$). All statistical analysis were conducted using STATA 13 (StataCorp©).

Results

Records for abiotic factors

The monthly minimum temperature on the orchard during the study period varied between 8.00 °C (June 2016) and 21.02 °C (December 2014). The monthly average and maximum temperatures varied between 17.48 °C (June 2016) and 27.52 °C (December 2015) and between 24.71 °C (August 2015) and 40.5 °C (February 2016), respectively. The total rainfall was 903.00 mm and 835.00 mm during the first mango season and the second mango season, respectively.

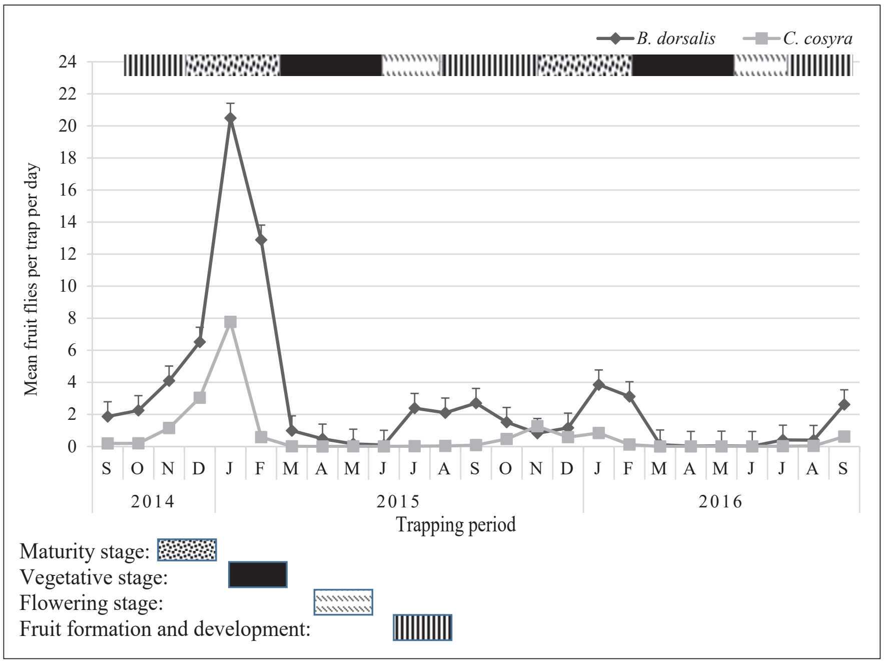

Figure 3. Seasonal fluctuation (means ± standard errors) of the populations of *Bactrocera dorsalis* and *Ceratitis cosyra*, along the phenology stages of mango in the studied orchard.

Mango phenology

Study results showed that the vegetative growth stage of mango began in March and extended until May. The flowering stage started in June and ended in July–August. In August began the fruit growing stage, which extended till October. In November the fruit entered the maturity stage, lasting till February. The peak of maturity of mango was observed in December and January (Figure 3). No differences were observed between the two mango seasons.

Fluctuation of fruit flies population in the orchard

Bactrocera dorsalis was present in the orchard during the whole trapping period (Figure 3). *Ceratitis cosyra* was present throughout most of the trapping period, being absent only in October 2014, April 2015 and March 2016 (Figure 3). Trap catches of both species varied throughout the years. Two peaks of abundance were observed during the trapping period for each species. For *B. dorsalis*, the peaks were observed in January 2015 (FTD = 20.9) and January 2016 (FTD = 3.9). *Ceratitis cosyra* reached the peak of abundances in January 2015 (FTD = 7.77) and November 2015 (FTD = 1.27). In the first mango season, both species peaked at the same month (January 2015), while during the second mango season *C. cosyra* peaked two months before *B. dorsalis*. In general, low densities of flies were observed from March to June (*B. dorsalis*) and from March to September (*C. cosyra*).

When analyzing the abundance of flies over the phenology stages of mango in the orchard, for *B. dorsalis*, the maturity stage of the host coincided with higher fruit fly abundance (FTD = 6.90 ± 0.62) and was statistically different from other stages namely vegetative growth (FTD = 0.3 ± 2.19), flowering (FTD = 0.725 ± 2.69) and fruit formation and development stages (FTD = 2.00 ± 1.12), which had lower abundances and not significantly different from each other, based on the SNK test (Table 1).

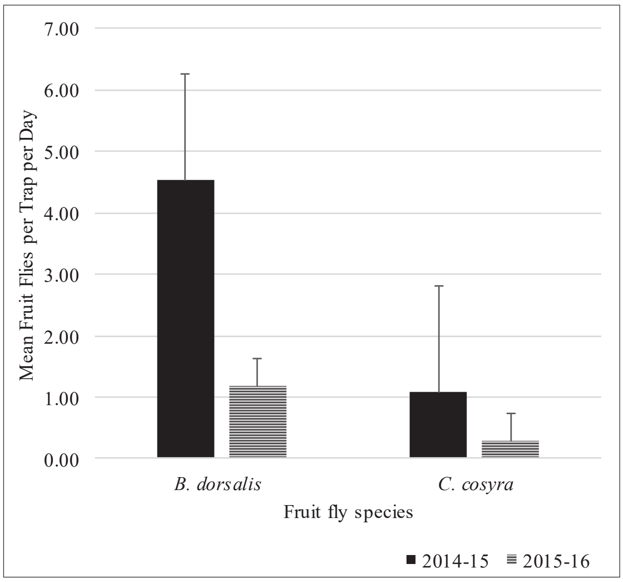

Figure 4. Fluctuation of the populations of *Bactrocera dorsalis and Ceratitis cosyra* over two mango seasons 2014–2015 and 2015–2016. Values are means ± standard errors (error bars).

Similar results were observed for *C. cosyra*, where the maturity stage of the host has the highest abundance (FTD = 2.12 ± 0.35) compared to other stages namely vegetative growth (FTD = 0.00 ± 0.85), flowering (FTD = 7.16e-17 ± 1.05) and fruit formation and development (FTD = 0.19 ± 0.45) (Table 2).

The target species showed significant variability between the years (Figure 4) with higher abundances of both *B. dorsalis* (Mann-Whitney $P = 0.000$) and *C. cosyra* (Mann-Whitney

Table 1. Number of fruit flies per trap and per day (FTD) of the population of *B. dorsalis* according to the phenology stage of mango in the orchard. Values are means and standard errors.

Phenology stages	FTD
Vegetative growth	0.30 ± 2.19 a
Flowering	0.725 ± 2.69 a
Fruit formation and development	2.00 ± 1.12 a
Fruit maturity	6.90 ± 0.92 b
	$P < 0.0015$; $F = 5.02$

Mean values followed by the same letter on the column are not significantly different by the Student Newman Keuls (SNK) test at 0.05 level.

Table 2. Number of fruit flies per trap and per day (FTD) of the population of *C. cosyra* according to the phenology stage of mango in the orchard. Values are means and standard errors.

Phenology stages	FTD
Vegetative growth	0.00 ± 0.85 a
Flowering	7.16e-17 ± 1.05 a
Fruit formation and development	0.19 ± 0.45 a
Fruit maturity	2.12 ± 0.35 b
	$P < 0.0015$; $F = 5.75$

Mean values followed by the same letter on the column are not significantly different by the Student Newman Keuls (SNK) test at 0.05 level.

Table 3. Comparison of the populations (number of fruit flies per trap and per day) of *Bactrocera dorsalis* and *Ceratitis cosyra* over two mango seasons (2014–2016).

Cropping seasons	*B. dorsalis*	*C. cosyra*
2014–2015	4.53 a	1.18 a
2015–2016	1.08 b	0.28 b
	z = 4.335; P < 0.0000	z = 2.640; P < 0.0083
Average	2.85 A	0.68 B
	z = 4.146; P < 0.000	

Mean values followed by the same lower case letter over the column and capital letter along the line are not statistically different from each other by the Mann-Whitney test at 0.05 level.

TABLE 4. Relations of the population dynamics of *Bactrocera dorsalis* and *Ceratitis cosyra* with several biotic and abiotic factors, using a Poisson log-linear regression.

Variables	*B. dorsalis*			*C. cosyra*		
	Coef.	S.E.	P > z	Coef.	S.E.	P > z
Minimum temperature	0.45	0.09	0.000*	0.68	0.33	0.0370*
Maximum temperature	-0.13	0.07	0.058 ns	0.22	0.25	0.382 ns
Average temperature	-0.37	0.13	0.005*	-0.56	0.35	0.102 ns
Mango phenology	0.56	0.18	0.001*	1.67	1.08	0.122 ns
Rainfall	-0.001	0.001	0.721 ns	-0.001	0.002	0.644 ns
Constant	4.95	2.08	0.017*	-11.26	10.46	0.282 ns
	N = 24; LR $chi^2(5) = 99.03$; Pseudo $R^2 = 0.59$; $P > chi^2 = 0.000$			N = 24; LR $chi^2(5) = 39.62$; Pseudo $R^2 = 0.58$; $P > chi^2 = 0.000$		

* Significant; ns: Not significant.

TABLE 5. Relative abundance index (RAI) of *Bactrocera dorsalis* and *Ceratitis cosyra* over the phenology stages of mango.

Phenology stages	RAI = 1	0.66 < RAI < 1	0.33 < RAI < 0.66	0 < RAI < 0.33	RAI = 0	*n*
Maturity	0	24	9	1	0	34
Vegetative	2	4	0	0	0	6
Flowering	0	4	0	0	0	4
Fruit formation and development	1	21	1	0	0	23

* Significant; ns: Not significant.

$P = 0.0083$) during the first cycle. When comparing the average density of the two species using SNK test we observed that *B. dorsalis* (FTD = 2.85) was significantly higher than *C. cosyra* (FTD = 0.68) (Table 3).

Correlation with biotic and abiotic factors

The peak of fruit flies population observed in January coincided with the peak of mango maturity in the orchard, while the peak observed in November coincided with the maturity of wild mango outside the orchard.

The fluctuation followed the same pattern as temperature and rainfall. Low densities of flies were observed when rainfall, minimal medium and maximum temperatures were also low. High densities of both species in January coincided with high rainfall and high minimum and average temperatures. The peak of *C. cosyra* in November coincided with low rainfall. However, the statistic relation of each factor with the fluctuation of the flies was different for each species.

Bactrocera dorsalis

The Poisson log-linear regression showed significant positive effect of minimum temperature and mango phenology stages on fluctuation of population of *B. dorsalis* and a negative effect of average temperature (df = 23, $chi^2 = 99.03$; $P < 0.000$) (Table 4). These results suggests that the abundance of *B. dorsalis* increases when minimum temperature increases, the host phenology changes from vegetative stage to mango maturity, and the average temperature decreases.

Ceratitis cosyra

Significant and positive relationships were observed between the fluctuation of population of *C. cosyra* and minimum temperature (df = 23, $chi^2 = 39.62$; $P < 0.000$). These results indicate that the population of *C. cosyra* increases only when the minimum temperature increases, but that it is not being affected neither by the maximum temperature, mango temperature, rainfall or host phenology.

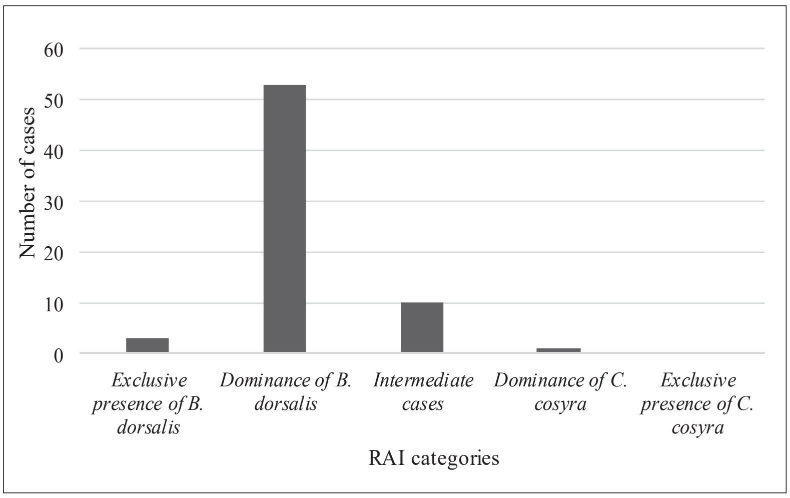

FIGURE 5. Number of cases that each category (see text for delimitation of the RAI categories) of the relative abundance index (RAI) was observed in the mango orchard.

Relative abundance index (RAI) of *B. dorsalis* and *C. cosyra*

The RAI showed relationships between the two target species, and the results are presented in Table 5 and Figure 5. *Bactrocera dorsalis* was the most abundant species in the orchard (average RAI = 0.814). From a total of 67 trapping dates, 3 cases of exclusive presence of *B. dorsalis* were observed, 53 cases of coexistence of *B. dorsalis* and *C. cosyra* but with *B. dorsalis* more abundant, 10 cases of intermediate cases (similar population level) and 1 case of coexistence with *C. cosyra* more abundant. There were no cases of exclusive presence of *C. cosyra*. The cases of exclusive presence of *B. dorsalis* were observed during the vegetative growth and fruit formation and development stages.

Discussion

Results of the study showed presence of fruit flies throughout the study period, with high abundances from November to February for both seasons. Similar results were reported by Majacunene (2014), when monitoring population of *B. dorsalis* by methyl eugenol in Manica Province, Mozambique. She observed high abundance of *B. dorsalis* from November to March, with peak in January. The peak reported coincided with host maturity, high average temperature and relative humidity. The main factor described by the author as responsible for the fluctuation of the population was the availability of mango, the main host of the fly. These results are consistent with Tan and Serit (1994), who concluded that the availability of preferred hosts is the variable that most influences the size of the population of adults of *B. dorsalis* in Malaysia. Similar results for *Anastrepha* species were observed by Aluja *et al.* (1996), who showed that the availability of hosts influenced the population abundances, where the peaks of three most important fruit fly species coincided with the period of greatest main host fruit production. Mwatawala *et al.* (2006) has reported that the population growth of *B. dorsalis* at SUA (Sokoine University of Agriculture) orchards in Tanzania, was directly related with the presence of mango and guava. Coledonio-Hurtado *et al.* (1995), Tan and Serit (1994) and Vayssières *et al.* (2005), have also noted and concluded that the availability of hosts, combined with climatic factors such as temperature and rainfall, play an important role in the fluctuation of population of fruit flies. However, Vayssières *et al.* (2015), had a different conclusion, reporting that the fluctuation of population of fruit flies is primarily related to the rainfall, and secondly to host availability. According to these authors, the first rainfalls is the most important factor for the increase of fruit flies abundance, which coincides with the pre-ripening stage of mango, which as secondary factor leads to the population explosion. Rainfall also affects the population of fruit flies by making the soil moist, providing favorable conditions for adults to hatch from the puparia (Pedigo, 1996). In Mozambique, the availability of the host plants (cultivated and non-cultivated), contributes to the continuous multiplication and prevalence of *B. dorsalis* throughout the year. The populations of *B. dorsalis* and *C. cosyra* show a decline when the temperature is low and adult flies become scarce in cold and dry periods. During hot and rainy season, the population increases until the end of the mango season (Cugala, 2011). *Ceratitis cosyra* was not captured for three trapping dates over vegetative stages of mango and the population peaked in different times during the two seasons of mango covered by the study. *Ceratitis cosyra* has not been detected during most of the vegetative stage of mango in Benin over five years of observations (Vayssières *et al.*, 2015), and in West Africa (Vayssières *et al.*, 2014). According to Leweniqila (1997), low population densities of fruit flies can be attributed to the drought condition through its effect on fruiting of plant species. During the first season, the peak of *C. cosyra* coincided with *B. dorsalis* peaks in January but during the second season, the peak of the species was observed in November, two months before *B. dorsalis* peaks. This observation is consistent with Vayssières *et al.* (2014, 2015) who reported peaks of *C. cosyra* weeks before *B. dorsalis* in all study locations namely Benin, Burkina Faso, Ivory Coast, Ghana, Guinea, Mali, Senegal and Togo, and trapping years. *Ceratitis cosyra* shows high abundances during the pre-maturity and maturity periods of early varieties of mangoes differently with *B. dorsalis* (Vayssières *et al.*, 2014). In the present study, local varieties of mango in the neighborhood had their maturation from October to December.

In the present study, the first season (2014/15) showed higher abundance of fruit flies of both species *B. dorsalis* and *C. cosyra* compared to the second season (2015/16). The differences of the fruit fly population in mango orchards from year to year may be linked to alternation in fruit bearing as described by Litz (1997) and Mwatawala *et al.* (2006), having years with high production and other years with low production (Vayssières *et al.*, 2015). Vayssières *et al.* (2015), consider that the fluctuation of population of tephritids year to year can also be attributed to the likely impact of intensive monitoring of the species. For good perception of fluctuation of fruit fly population from one year to another, four years of data collection are recommended in order to adapt to the wide variation in the trapping data, and also to take into account the direct impact of the hosts.

In relation to the differences of abundance of the flies over the mango phenology stages, the two species *B. dorsalis* and *C. cosyra* were present in the orchard during all phenology stages, with the highest abundances observed during the maturity stage. Vayssières *et al.* (2015) reported similar results with higher abundance of flies during the maturity stage (FTD = 408 ± 29.5), which were statistically higher comparing to other phenology stages namely fruit development (FTD = 154.6 ± 11.2), vegetative growth (FTD = 112.3 ± 7.7) which were not different between them and the flowering stage (FTD = 20.9 ± 5.6) with the lowest abundance. Previously, Vayssières *et al.* (2014) reported significant differences between the abundances of *B. dorsalis* and *C. cosyra* in different mango orchards in Benin, Burkina Faso, Ivory Coast, Ghana, Guinea, Mali, Senegal and Togo, with the host maturity stage with the highest abundance of *B. dorsalis* (FTD = 84.76 ± 10.79), followed by vegetative growth stage (FTD = 31.12 ± 04.02), and pre-maturity stage (FTD = 3.76 ± 0.68) which were not different among themselves, and the growth stages of fruit (FTD = 0.83 ± 12.22) which were not different with flowering stages (FTD = 0.77 ± 12.11). For *C. cosyra*, the maturity stage (FTD = 37.25 ± 5.64) and pre-maturity stage (FTD = 34.49 ± 8.41) had the highest abundances, followed by fruit growth stage (FTD = 21.33 ± 3.77), flowering stage (FTD = 5.67 ± 1.64) and vegetative growth stage (FTD = 0.65 ± 0.16). The abundance or presence of *B. dorsalis* and *C. cosyra* in all phenology stages of the host can be related to the existence of a low abundance population in the orchard during the period without fruit production, which restores the population during the favorable conditions, due to the high fecundity of tephritid females (Malavasi and Morgante, 1980). Another factor that this phenomenon can be related with is the existence of alternative hosts like guava outside of the orchard which act as a reservoir host during the period that there is no host in the main orchard (Mwatawala *et al.*, 2009b).

Data from RAI index and Mann-Whitney tests suggest that the invasive species *B. dorsalis* was dominant in the orchard compared to the native species *C. cosyra.* RAI index has been used by Segura *et al.* (2006), when studying the abundance relation of *C. capitata* and *Anastrepha fraterculus* in Argentina, where they reported a dominance of the invasive species over the native one (RAI = 0.98). The dominance of *B. dorsalis* over the native species *C. cosyra* was also been reported in Benin (Vayssières *et al.*, 2015), West African countries (Vayssières *et al.* 2014), Tanzania (Mwatawala *et al.*, 2009a) and Kenya (Ekesi *et al.*, 2009). The latter study provided evidence for the mechanism of actual displacement of the native species by the invasive one. Even though RAI results indicate that *B. dorsalis* has dominated *C. cosyra*, further studies are necessary to understand the process and factors underlying the species displacement. However at this stage it can be stated that *B. dorsalis* has the potential to displace the native *C. cosyra* in the study area.

The relationship between the seasonal fluctuation of fruit flies with abiotic and biotic factors can be analyzed through correlation or regression analysis (Nene *et al.*, 2016). Studies show that this relationship varies throughout the region. In Benin, a positive relationship of *B. dorsalis* abundance with the minimum and maximum temperature, relative humidity and rainfall was reported by Vayssières *et al.* (2009). Studies carried out in China showed that the rainfall was the abiotic factor with stronger positive relationship with population abundance of *B. dorsalis* (Chen *et al.*, 2006). In India, a positive relationship of relative humidity and rainfall with the abundance of *B. dorsalis*, *B. zonata,* and *B. corecta* was reported by Sarada *et al.* (2001). Similarly, Shukla and Prasad (1985) showed a positive relationship of the population of *B. dorsalis* with maximum temperature and relative humidity. Agarwal and Kumar (1999) showed a strong positive relationship between the population of *B. zonata* and temperature and rainfall. Regarding *C. cosyra*, Vayssières *et al.* (2009) reported a positive relationship between the population of the species and minimum temperature and rainfall. Vayssières *et al.* (2005) showed a positive relationship of the population of *C. cosyra* and maximum temperature, relative humidity and rainfall. However, with all these variations in the relationship between the populations of fruit flies with climatic factors, rainfall shows to be the abiotic factor to have more consistently a positive relationship with fruit flies, although it can sometimes be a negative one (Vayssières *et al.*, 2009).

Temperature is also an important factor for fruit fly population since it may influence direct or indirectly to the rate of development, mortality and fecundity (Corsato, 2004). The absence of positive relationship between the population of *C. cosyra* and rainfall reported in the present study may be justified based on studies showing that *C. cosyra* has a preference for dry or low humidity periods. Although the relative humidity has not been studied, this has a direct relationship with rainfall. According to Vargas *et al.* (1993), the abundance of species of the genus *Ceratitis* in Hawaii, seemed to be negatively related with rainfall. In drier areas the number of individuals collected by traps was higher. However, the absence of soil moisture may cause mortality of pupae and the newly emerged adults, who have difficulty crossing the dry soils (Baker *et al.*, 1944). The positive relationship between *B. dorsalis* and *C. cosyra* with the phenology of mango observed in this study is obvious, because the dependence of fruit for reproduction and feeding (Mwatawala *et al.*, 2006; Diatta *et al.*, 2013).

Conclusion

The population of *Bactrocera dorsalis* and *Ceratitis cosyra* in Mozambique fluctuated throughout the year and *B. dorsalis* was more abundant than *C. cosyra* with some periods of exclusive presence of *B. dorsalis*. This fluctuation was related to biotic and abiotic factors. Understanding the relationship between population fluctuations and biotic and abiotic factors is important for anticipating the build-up of pest populations at the start of the season. As such it can assist the growers in predicting population growth and taking precautionary measures.

Acknowledgments

The authors are thankful to the Belgian Development Agency for the funding of the S1_Tnz_Moz_IPM Project, through the framework agreement with the Royal Museum of Central Africa; to Eduardo Mondlane University, Faculty of Agronomy and Forest Engineering and Sokoine University of Agriculture for the technical assistance; and to technicians from the National Fruit Fly Laboratory, Provincial Directorate of Agriculture and Food Security of Manica, for their help during the field work.

References

Agarwal, M.L., and Kumar, P. (1999). Effect of weather parameters on population dynamics of peach fruit fly, *Bactrocera zonata* (Saunders). Entomon *24*, 81–84.

Aluja, M., Celedonio, H., Liedo, P., Cabrera, M., Castillo, F., Guillém, J., and Rios, E. (1996). Seasonal population fluctuations and ecological implications for management of *Anastrepha* fruit flies (Diptera: Tephritidae) in commercial mango orchards in southern Mexico. J. Econ. Entomol. *89*, 654–667. https://doi.org/10.1093/jee/89.3.654.

Baker, A.C., Stone, W.E., Plummer, C.C., and McPhail, M. (1944). A review of studies on the Mexican fruit fly and related Mexican species. U.S. Dept. Agr. Misc. Publ. *531*, 155 pp.

Bota, L.D. (2016). Avaliação da dinâmica populacional e infestação da manga por moscas da fruta. M.Sc. Thesis (Mozambique: Universidade Eduardo Mondlane, Imprensa Universitária), 111 pp.

Chen, P., Ye, H., and Liu, J. (2006). Population dynamics of *Bactrocera dorsalis* (Diptera Tephritidae) and analysis of the factors influencing the population in Ruili, Yunna Province, China. Acta Ecol. Sin. *26*, 2801–2808. https://doi.org/10.1016/S1872-2032(06)60044-9.

Coledonio-Hurtado, H., Aluja, M., and Liedo, P. (1995). Adult population of *Anastrepha* species (Diptera: Tephritidae) in tropical orchard habitats of Chiapas, Mexico. Entomol. Soc. Am. *24*, 861–869.

Correia, A.R.I., Rego, J.M., and Olmi, M. (2008). A pest of significant economic importance detected for the first time in Mozambique: *Bactrocera invadens* Drew, Tsuruta & White (Diptera: Tephritidae: Dacinae). Boll. Zool. Agr. Bachicolt., Serie II *40*(1), 9–13.

Corsato, C.D.A. (2004). Moscas das frutas (Diptera: Tephritidae) em pomares de goiaba no norte de Minas Gerais: biodiversidade, parasitóides e controle biológico. M.Sc. Thesis (Piracicaba, São Paulo, Brasil: Universidade de São Paulo), 83 pp.

Cugala, D.R. (2011). Management and mitigation measures for alien invasive fruit fly (*Bactrocera invadens*) in Mozambique. Terminal Statement prepared for the Government of Mozambique and the Department of Plant Protection (Food and Agriculture Organization of the United Nations [FAO]).

Diatta, P., Rey, J.Y., Vayssieres, J.F., Diarra, K., Coly, E.V., Lechaudel, M., and Ndiaye, O. (2013). Fruit phenology of citruses, mangoes and papayas influences egg-laying preferences of *Bactrocera invadens* (Diptera: Tephritidae). Fruits *68*(6), 507–516. https://doi.org/10.1051/fruits/2013093.

Ekesi, S., Billah, M.K., Nderitu, P.W., Lux, S., and Rwomushana, I. (2009). Evidence for competitive displacement of *Ceratitis cosyra* by the invasive fruit fly *Bactrocera invadens* (Diptera: Tephritidae) on mango and mechanisms contributing to the displacement. J. Econ. Entomol. *102*(3), 981–991. https://doi.org/10.1603/029.102.0317.

Ekesi, S., Mohamed, S.A., and De Meyer, M., eds. (2016). Fruit Fly Research and Development in Africa – Towards a Sustainable Management Strategy to Improve Horticulture (Springer), 777 pp. https://doi.org/10.1007/978-3-319-43226-7.

FAOSTAT (2015). FAO Statistics Division (accessed December 5, 2015). http://www.fao.org/faostat/en/#data/QC.

Goergen, G., Vayssières, J.F., Gnanvossou, D., and Tindo, M. (2011). *Bactrocera invadens* (Diptera: Tephritidae), a new invasive fruit fly pest for the Afrotropical region: host plant range and distribution in West and Central Africa. Envir. Entomol. *40*(4), 844–854. https://doi.org/10.1603/EN11017.

IAEA (2013). Trapping guidelines for area-wide fruit fly programmes. (Vienna, Austria: International Atomic Energy Agency. Insect Pest Control Section, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture), TG/FFP-2013.

José, L., Cugala, D., and Santos, L. (2013). Assessment of invasive fruit fly fruit infestation and damage in Cabo Delgado province, northern Mozambique. African Crop Sci. J. *21*(1), 21–28.

Leweniqila, L., Heimoana, V., Purea, M., Munro, L., Allwood, A.J., Ralulu, L., and Tora Vueti, E. (1997). Seasonal abundances of *Bactrocera facialis* (Coquillet), *B. passiflorae* (Froggatt), *B. xanthodes* (Broun), *B. melanotus* (Coquillet) in orchard and forest habitats. In Management of Fruit Flies in the Pacific, A.J. Allwood, and R.A.I. Drew, eds. (Canberra: ACIAR), p. 121–124.

Litz, R.E. (1997). The Mango: Botany, Production and Uses. (Cambridge, United Kingdom: CAB International).

MAE (2005). Perfil do Distrito de Manica. http://www.ine.gov.mz/documentos/outros-documentos/perfil-do-distrito-de-manica-manica.pdf/view.

Majacunene, A.P. (2014). Avaliação do impacto da estratégia de maneio integrado na população da mosca invasiva da fruta, *Bactrocera invadens*, na província de Manica. M.Sc. Thesis (Mozambique: Universidade Eduardo Mondlane, Imprensa Universitária), 88 pp.

Malavasi, A., and Morgante, J.S. (1980). Biologia de moscas-das-frutas (Diptera: Tephritidae). II: índices de infestação em diferentes hospedeiros e localidades. Rev. Bras. Biol. *40*(1), 17–24.

Manrakhan, A., Daneel, J.-H., Beck, R., Virgilio, M., Meganck, K., and De Meyer, M. (2017). Efficacy of trapping systems for monitoring of Afrotropical fruit flies. J. Appl. Entomol. *141*(10), 825–840 https://doi.org/10.1111/jen.12373.

Mayamba, A., Nankinga, C.K., Isabirye, B., and Akol, A.M. (2014). Seasonal population fluctuations of *Bactrocera invadens* (Diptera: Tephritidae) in relation to mango phenology in the Lake Victoria Crescent, Uganda. Fruits *69*, 473–480. https://doi.org/10.1051/fruits/2014033.

Mwatawala, M.W., De Meyer, M., Makundi, R.H., and Maerere, A.P. (2006). Seasonality and host utilization of the invasive fruit fly, *Bactrocera invadens* (Diptera: Tephritidae) in central Tanzania. J. Appl. Entomol. *130*(9–10), 530–537. https://doi.org/10.1111/j.1439-0418.2006.01099.x.

Mwatawala, M., De Meyer, M., Makundi, R.H., and Maerere, A.P. (2009a). An overview of *Bactrocera* (Diptera: Tephritidae) invasions and their speculated dominancy over native fruit fly species in Tanzania. J. Entomol. *6*, 18–27. https://doi.org/10.3923/je.2009.18.27.

Mwatawala, M.W., De Meyer, M., Makundi, R.H., and Maerere, A.P. (2009b). Host range and distribution of fruit-infesting pestiferous fruit flies (Diptera: Tephritidae) in selected areas of Central Tanzania. Bull. Entomol. Res. *99*(6), 629–641. https://doi.org/10.1017/S0007485309006695.

Nene, W.A., Rwegasira, G.M., and Mwatawala, M.W. (2016). Temporal abundance of African weaver ant, *Oecophylla longinoda* (Hymenoptera: Formicidae) under unimodal rainfall pattern in Tanzania. Biocontrol Sci. Technol. *26*(4), 539–547. https://doi.org/10.1080/09583157.2015.1133806.

Pedigo, L.P. (1996). Entomology and Pest Management, 2nd edn. (London: Prentice Hall).

Sarada, G., Maheswari, T.U., and Purushotham, K. (2001). Seasonal incidence and population fluctuation of fruit flies in mango and guava. Indian J. Entomol. *63*, 272–276.

Segura, D.F., Vera, M.T., Cagnotti, C.L., Vaccaro, N., De Coll, O., Ovruski, S.M., and Cladera, J.L. (2006). Relative abundance of *Ceratitis capitata* and *Anastrepha fraterculus* (Diptera: Tephritidae) in diverse host species and localities of Argentina. Ann. Entomol. Soc. Am. *99*(1), 70–83. https://doi.org/10.1603/0013-8746(2006)099[0070:RAOCCA]2.0.CO;2.

Shukla, R.P., and Prasad, V.G. (1985). Population fluctuations of the oriental fruit fly, *Dacus dorsalis* Hendel, in relation to hosts and abiotic factors. Trop. Pest Mgt. *31*, 273–275. https://doi.org/10.1080/09670878509370999.

Tan, K., and Serit, M. (1994). Adult population dynamics of *Bactrocera dorsalis* (Diptera: Tephritidae) in relation to host phenology and weather in two villages of Penang Island, Malaysia. Environ. Entomol. *23*, 267–275. https://doi.org/10.1093/ee/23.2.267.

Uchida, G.K., Walsh, W.A., Encarnacion, C., Vargas, R.I., Stark, J.D., Beardsleyn, J.W., and McInnis, D.O. (1996). Design and relative efficiency of Mediterranean fruit fly. J. Econ. Entomol. *89*(5), 1137–1142. https://doi.org/10.1093/jee/89.5.1137.

Vargas, R.I., Stark, J.D., Uchida, G.K., and Purcell, M. (1993). Opiine parasitoids (Hymenoptera: Braconidae) of oriental fruit fly (Diptera: Tephritidae) on Kauai island, Hawaii: Island wide relative abundance and parasitism rates in wild and orchard guava habitats. Environm. Entomol. *22*, 246–253. https://doi.org/10.1093/ee/22.1.246.

Vayssières, J.F., Goergen, G., Lokossou, O., Dossa, P., and Akponon, C. (2005). A new *Bactrocera* species in Benin among mango fruit fly (Diptera: Tephritidae) species. Fruits *60*, 371–377. https://doi.org/10.1051/fruits:2005042.

Vayssières, J.F., Korie, S., Temple, L., and Boueyi, S.P. (2008). The mango tree in central and northern Benin: cultivar inventory, yield assessment, infested stages and loss due to fruit flies (Diptera: Tephritidae). Fruits *63*, 335–348. https://doi.org/10.1051/fruits:2008035.

Vayssières, J.F., Korie, S., and Ayegnon, D. (2009). Correlation of fruit fly (Diptera: Tephritidae) infestation of major mango cultivars in Borgou (Benin) with abiotic and biotic factors and assessment of damage. Crop Prot. *28*(6), 477–488. https://doi.org/10.1016/j.cropro.2009.01.010.

Vayssières, J.F., Sinzogan, A., Adandonon, A., Rey, J.Y., Dieng, E.O., Camara, K., Sangaré, M., Ouedraogo, S., Hala, N., Sidibé, A., Keita, Y., Gogovor, G., Korie, S., Coulibaly Kikissagbe, C., Toussou, A., Bilah, M., Biney, K., Nobime, O., Diatta, P., N'dépo, R., Noussourou, M., Traoré, L., Saizonou, S., and Tamo, M. (2014). Annual population dynamics of mango fruit flies (Diptera: Tephritidae) in West Africa: Socio-economic aspects, host phenology and implications for management). Fruits *69*, 207–222. https://doi.org/10.1051/fruits/2014011.

Vayssières, J.F., De Meyer, M., Ouagoussounon, M., Sinzogan, A., Adandonon, A., Korie, S., Wargui, R., Anato, F., Houngbo, H., Didier, C., De Bon, H., and Goergen, G. (2015). Seasonal abundance of mango fruit flies (Diptera: Tephritidae) and ecological implications for their management in mango and cashew orchards in Benin (Centre & North). J. Econ. Entomol. *108*(5), 2213–2230. https://doi.org/10.1093/jee/tov143.

Virgilio, M., White, I., and De Meyer, M. (2014). A set of multi-entry identification keys to African frugivorous flies (Diptera, Tephritidae). ZooKeys, *428*, 97–108. https://doi.org/10.3897/zookeys.428.7366.

Virgilio, M., Manrakhan, A., Delatte, H., Daneel, J.-H., Mwatawala, M., Meganck, K., Barr, N., and De Meyer, M. (2017). The complex case of *Ceratitis cosyra* (Diptera, Tephritidae) and relatives. A DNA barcoding perspective. J. Appl. Entomol. *141*(10), 788–797. https://doi.org/10.1111/jen.12379.

Received: Feb. 2, 2018
Accepted: May 16, 2018