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Research

Possibilities of competitive displacement of *Bactrocera dorsalis* (Hendel) by *Bactrocera zonata* (Saunders) (Tephritidae: Diptera) in guava *Psidium guajava* ecosystem in Sudan

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Abstract
Oriental fruit fly (OFF) *Bactrocera dorsalis* and peach fruit fly (PFF) *Bactrocera zonata* are the most notorious pests that invaded Sudan in 2005 and 2012, respectively, causing severe losses and hindering horticultural production and exports. Prior to 2012, OFF was the most abundant fly in guava orchards in Gezira State. Monitoring fruit flies to determine species composition, seasonality, and possibilities of competitive displacement was conducted in two guava (*Psidium guajava*) orchards in Gezira State; Fadasi and Gezirat Elfil, using food bait attractant and rearing flies from infested fruits..Longevity and survival percentages of developmental stages of the two species were also determined. Monitoring fly populations using Torula yeast and rearing of fruit flies from guava fruits revealed that OFF and PFF were the most prevalent species in guava ecosystem at both sites. At the Fadasi site, PFF was the predominant species representing (99.3%) of the guild of the trapped flies with an infestation level of 99.6%) flies/kg of guava fruits. At G. Elfil, OFF comprised 80.8% of the trapped flies with infestation level ca 53.6% while 19.2% of trapped flies were *B. zonata* with 46.4% infestation level. The high percentage of trapped OFF at G. Elfil might be attributed to multi-cropping system in the area. Developmental stages of PFF were shorter than that of OFF by 9.2 days, while its survival percentage was higher than that of OFF for all developmental stages. Competitive displacement of OFF by PFF in guava orchards at Fadasi site may have occurred as a result of the mono-cropping system, short developmental period, and high survival percentage of developmental stages of PFF on guava compared to that of OFF.

Keywords Peach fruit fly · Oriental fruit fly · Niche portioning · Guava · Sudan

1 Introduction

Fruit flies of the family Tephritidae are the most serious pests of horticultural crops all around the world. They attack several fruits and vegetables causing severe losses. In tropical regions, their economic importance is highly recognized where they caused 80% losses to the tropical fruits which hindered the exportation of the produce to the European and Arab countries [1] thus, reducing the flow of hard currency to African countries. For small farmers, fruit flies decreased the quality of their fruits if left without control and increased the cost of production through application of insecticides. Many indigenous species of fruit flies were reported attacking different horticultural crops,

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among them the Mediterranean fruit fly or medfly (*Ceratitis capitata* (Weidmann)), Mango fruit fly or Marula fruit fly (*C. cosyra* (Walker)), Rhodesian fruit fly (*C. quinaria* (Bezzi), Cucurbit fruit flies, *Dacus vertebrates* (Bezzi) and *D. ciliatus* Loew, Apple of Sodom fly, *D. longistylus* (Wiedemann) and Jujube or Chinese date fruit fly, *Carpomya incomplete* [2–4]. In the last two decades, the horticultural sector of Sudan was seriously affected by invasive species of fruit flies such as the Oriental fruit fly *Bactrocera dorsalis* (Hendel), formerly known as the invasive fruit fly *B. invadens* Drew Tsuruta and White, the melon fly *Zeugodacus cucurbitae* (Coquillett) and *D. punctatifrons* in 2005 [7]

Fruit flies of genus *Bactrocera* are known as the most serious alien invasive pests of tropical and subtropical fruits. They were recorded on more than 50 cultivated and wild plant species, mainly those with fleshy fruits including guava, mango, peach, apricot, fig and citruses [8] and [9]). These pests are widely spread in Asia and their status as quarantine pest has major consequences on losses of export markets due to the restrictions imposed to importing countries on any host or potential host plants of these fruit flies.

Study of seasonal abundance of insect pests is an essential component for determining the time of increase and/or decrease of population during the year, in order to plan for control strategies [10]. Abundance of species of fruit fly depends on the availability of host fruits, relative humidity, temperature and natural enemies. As stated by [11] and [12], the oviposition behaviour of fruit flies playing a vital role in the selection of proper host fruits and the choice to oviposit, depend on physical and chemical factors associated with fruits [13–16].

The principle of competitive exclusion is already present in Darwin's theory of natural selection. Based on field observations, Joseph Grinnell formulated the principle of competitive exclusion in 1904: "Two species of approximately the same food habits are not likely to remain long evenly balanced in numbers in the same region, one will crowd out the other".

Since detection of *B. zonata* in Sudan in 2012, no studies have been undertaken to investigate its seasonal abundance, levels of infestation it caused and determining of the changes on the fruit fly fauna after its invasion. Therefore, the present study was initiated to obtain detailed information on the seasonal abundance of *B. zonata,* infestation levels it caused, determining the changes on the fauna of fruit flies, determine possibilities of competitive displacement between the two species as well as discuss the effect of longevity and survival percentages of developmental stages of these fruit flies on this phenomenon.

2 Materials and methods

2.1 Sites of the study

This study was carried out from 2015 to 2017at Fadasi (14 53 33 N 33 46 67 E, altitude 402 m above sea level) and G. Elfil (14 26 56 N 3329 52 E, altitude 402 m above sea level) in the Gezira State, Sudan. Both areas are located on the western bank of the Blue Nile at 28 Kilometer distance from each other, where guava is the main horticultural produce with some mango trees at G. Elfil. Total area estimated was 2.5 ha for each site and distance between trees was 6 m. Blue Nile is the main source of water for irrigation at both sites. *B. dorsalis* was the dominant fruit fly in both study sites since 2005 according to the annual reports of Plant Protection Directorate (PPD) of Gezira state.

2.2 Seasonal abundance of *B. zonata* and *B. dorsalis*

To determine the fluctuations of fruit flies, four McPhail traps were distributed in both guava orchards in Fadasi and G. Elfil sites with a distance of 25 m in between, traps were baited with Torula yeast®ISCA Technology, Riverside, CA); potent to attract both species [17] at rate of 8 g/trap (diluted in 300 ml of water) and were hung on trees at a height of 1.5 to 2 m above ground. Traps were serviced weekly, cleaned and renewed with new attractant. The caught flies were preserved in 70% alcohol in plastic tubes and transferred to the laboratory of the Integrated Pests Management Research and Training Centre of Agricultural Research Corporation (ARC). In the laboratory, flies were sorted out, identified, sexed, counted and flies/trap/day was determined.

2.3 Larval infestation of guava fruits by *B. zonata* and *B. dorsalis*

This study was conducted to give detailed information on the infestation levels of guava by Tephritid fruit flies and to confirm that the caught species in trapping are the same species that cause the damage to fruits. On a weekly basis, guava fruits from the trees or the ground around the trees were collected in same time of traps change, weighed and incubated in plastic containers (15 X15X15 cm) on a layer of sterile sand to facilitate development of larvae to pupae. The containers were covered with muslin cloth for ventilation, and then emerged puparia were placed in Petri dishes (9 cm diameter) on a layer of sand which kept wetted up to the emergence of the adults. The emerged adults were placed in cages 30X30X30 composed of Plexiglas, wood and muslin cloth. Insects inside cages were equipped with water-impregnated cotton wicks in plastic tubes as a source of water and provided with sugar and protein hydrolysate as food source [18].

The emerged flies were identified using the pictorial Key of [18] then flies were sexed and females' ratio was counted. Infestation level of guava fruits by fruit flies was assessed as No of fruit flies per kg of fruit/s.

T-test was conducted to determine the differences between the mean numbers of *B. zonata* and *B. dorsalis* trapped during the study period as well as to determine the differences between the levels of infestation of guava fruit by the both above mentioned fruit fly species.

For both seasonality and level of infestation, Test statistical analysis was used to determine the significant difference between the population of the two fruit fly species using SAS 12 Software.

2.4 Longevity and survival percentages of developmental stages of *B. zonata* and *B. dorsalis*

To determine longevity and survival percentage of developmental stages of *B. zonata* and *B. dorsalis*, 10 pairs of females and males from both species were provided with guava fruits for egg laying in 30X30X30 cm plexage cages in laboratory of the Agricultural Research Corporation, Wad Medani under 25 ˚C ± 1temperature and 60 ± 5% relative humidity. Eggs that were laid by females, were gently removed from the fruits using camel hair brush and 100 of each species were injected in guava fruits using micropipettes, replicated three times and observed to the emergence of larvae which were removed and placed in a new fruits and monitored up to the emergence of puparia. The emerged puparia were kept in sand in Petri dishes and moistened and left until the emergence of adults. The duration for each stage was recorded and the survival percentages for each stage of both species was counted applying the following formula $\text{Survival percentage}(\%) = \frac{\text{Total individulas}-\text{Dead individulas}}{\text{Total individuals}} \times 100$

3 Results

Trapping fruit flies using Torula yeast at Fadasi and G. Elfil, Gezira State, Sudan revealed the presence of *B. zonata*, *B. dorsalis*, *C. quinaria, Z. cucurbitae*, *D. ciliatus* and *D. vertebrates*. All species were dominating the two sites of the study. However, *B. zonata* and *B. dorsalis* were reared out from guava fruits in the laboratory.

3.1 Fadasi site

3.1.1 Seasonal abundance of *B. zonata* and *B. dorsalis*

Figure 1 shows the result of seasonal abundance of fruit flies trapped to Torula yeast at Fadasi Site. Obviously, the population of *B. zonata* started in the 1st of November 2015 with 8.7 FTD and with the elapse of time increased to reach 10 FTD for the period from 9th of November 2015 to 24th of October 2016.

Population of *B. zonata* increased rapidly in the 9th of November 2016 (35.5) FTD and crested with (39.6 and 40.9) FTD during the end of November and first week of December of 2016 respectively then it decreased to 18.5 FTD at the end of the study in 28th of December. While, population of *B. dorsalis* was very low for the whole study period compared to that of *B. zonata*. On the 1st of November 2015 population of Oriental fruit fly started with 5 FTD, then decreased significantly (0.1 to 0.5 FTD).during the period from mid of December 2015 up to the end of the study period.

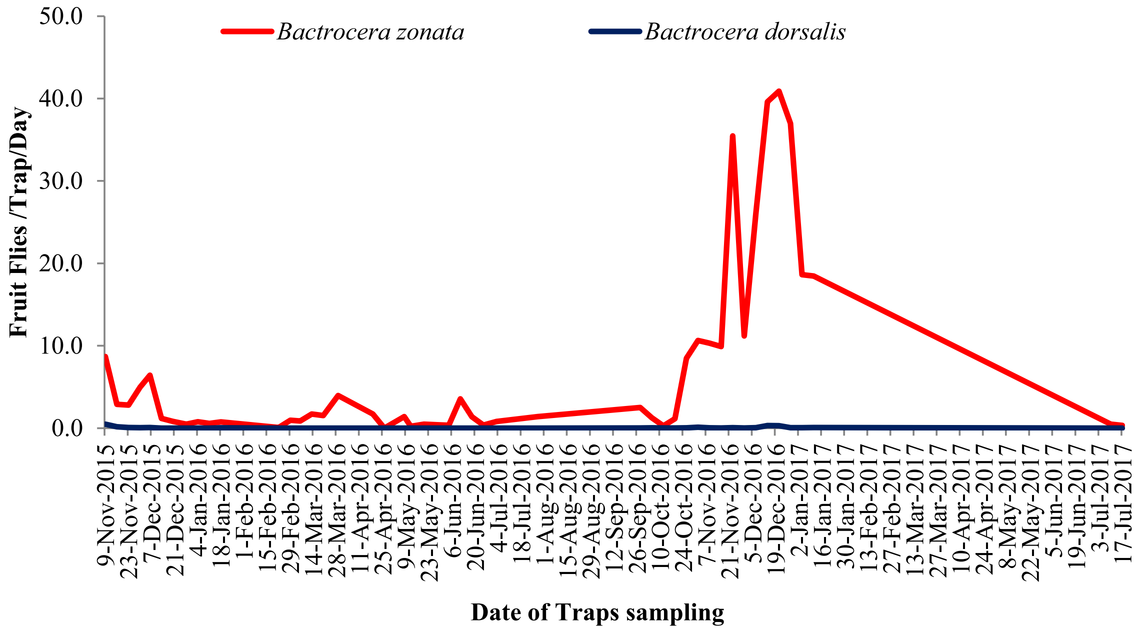

Fig. 1 Mean No of *B. zonata*and *B. dorsalis*/ Trap/Day at Fadasi site using Torula yeast Food bait attractant9th Nov 2015 to 17th July 2017

Statistical analysis for the populations of both fruit flies using t.test concluded that *B. zonata* was more abundant than *B. dorsalis* at 0.01 and 0.05 probabilities and the obtained value (4.24) is greater than Pr >|t|0.0001.The results of trapping revealed that, females represented (70.5%) from the total population of *B. zonata*.

3.2 Level of infestation of guava fruits by *B. zonata* and *B. dorsalis* (Fruit Flies/Kg of fruits)

Only *B. zonata* (99.6%) and *B. dorsalis* (0.4%) were reared out from guava fruits at Fadasi area during the study period from November 2015 to December 2016. The highest infestation level recorded for guava during the study period was 711.2 FF/Kg of fruits (Mean = 204 FF/Kg of fruits) and females represented 55.5%. While the highest infestation level of guava by *B. dorsalis*was10 FF/Kg as (Mean = 0.8 FF/Kg of fruits). Fluctuation of the infestation level for both species is shown in (Fig. 2). The infestation level of guava fruits by *B. zonata* started with (150 FF/Kg) of fruits for the period from 12th October to 12th of December 2015 and then altered from (200FF/kg)during the second third of December 2015 to (400 FF/kg)at the end of January 2016.

During the period from February to April 2016, infestation level of guava by *B. zonata* decreased drastically-to its lowest levels (2 and 38FF/kg) and started to increase gradually for the period from 18th May 2016 to 12th of June 2016(86.3to 428.6 FF/Kg) after that it was decreased to 125 FF/kg between 18th May 2016 and 12th of June 2016 then increased gradually to (335 FF/kg)for the period from 3rd of August 2016 up to the end of the study in 19th of December 2016.

No *B. dorsalis* was reared out from guava fruits from the onset of the experiments on the 1st of November 2015 up to the 2nd of June 2016. The infestation level by *B. dorsalis* fluctuated between 1 to 6.4 FF/Kg of fruits for the period from 11thof June 2016 to 28th of December 2016.

Analysis for the infestation levels of guava revealed significant differences between the infestation levels of guava by the two fruit fly species when t. test statistical analysis was applied.

Level of infestation of guava by *B. zonata* at Fadasi site was greater than that of *B. dorsalis* at 0.01 and 0.05 probabilities and the obtained value was greater than P >|t|0.0001.

3.3 G. Elfil site

3.3.1 Seasonal abundance of *B. zonata* and *B. dorsalis*

At this site, the results of trapping fruit flies from November, 2015 to December, 2016 revealed the presence of *B. dorsalis* and *B. zonata* with relative abundance 80.8% and8.7%, respectively.

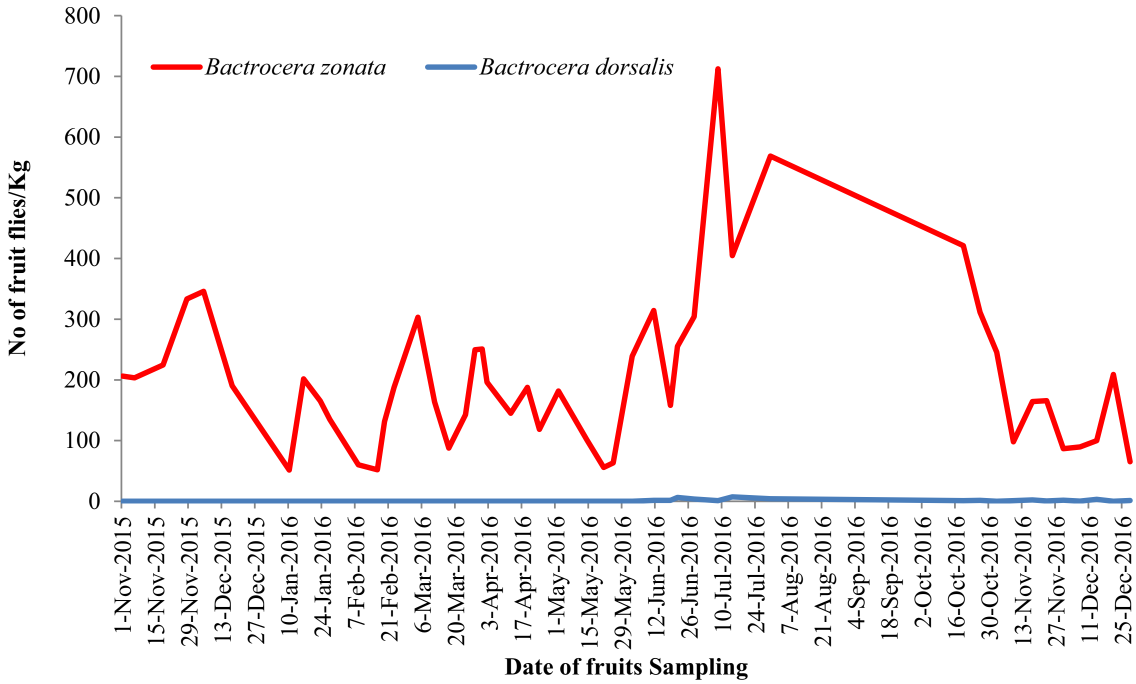

Fig. 2 Infestation Levels of guava fruits (Fruit fly/Kg of fruits) by *B. zonata* and *B. dorsalis* at Fadasi site (1st Nov 2015 to 25th Dec 2017)

The population of *B. dorsalis* was less than 10 FTD from 18th April 2015 to 25th April 2016 then increased to plateau at 16 FTD during the first three weeks of May 2016 and in the last week of the same month it peaked to 28.6 FTD. The population decreased to very low level in June and suddenly increased in the first week of July to reach the highest peak for all the study period with 49.9 FTD then decreased, fluctuated and peaked three times with 32 FTD during 20th of October, 3rd and 24th of November 2016 and fluctuated between 9.1 to 23 FTD up to the end of the study on 1st of April 2016. *B. dorsalis* was crested in May, July and December of 2016 at G. Elfil.

The population of *B. zonata* started with very few numbers 0.5 FTD from 18th October2015 to 25th April 2016 then increased gradually to 1.9 FTD in 25/4/2016 and fluctuated between 1.5 to 1.7 FTD from 2/5 to 18/5 2016 then increased to 2.8 FTD in 25/5/2016.

In the 2nd of July 2016 population of *B. zonata* reached the highest peak 6.8 FTD then fluctuated between 0.4 and 1.3 for the remained period which ended in 28th of December 2016 (Fig. 3).

T-test confirmed that, significantly the caught flies of *B. dorsalis* in traps was greater than that of *B. zonata* $P > |t| < 0.0001$.

3.4 Level of infestation of guava fruits by *B. zonata* and *B. dorsalis* (Fruit Flies/Kg of fruits)

Only *B. zonata* and *B. dorsalis* were reared out from guava fruits ca 47.5% and 52.5% for each species respectively. The mean percentage of infestation levels of guava fruits by *B. zonata* and *B. dorsalis* for all the study period was (419.1and 465.1FF/Kg of fruits respectively. Last week of June 2016 recorded the highest infestation levels by *B. zonata* and *B. dorsalis* with (2406 and 1833 FF/Kg) of fruits respectively for both species. On other hand the results indicated that, the percentage of females is greater than males representing (58.4%)for *B. zonata* and (58.3%) for *B. dorsalis*.

Figure 4. shows the fluctuation of infestation levels of guava (FF/Kg of Fruits) by both species of fruit flies. The infestation level peaked in December 2015, May 2016 and crested in June and decreased slightly in October and first of November of 2016. The results of rearing fruit flies from fruits indicated that, the sex ratios for both species were1.6:1 and 1.3:1 (females: males) for *B. zonata* and *B. dorsalis* respectively.

As indicated by the t-test analysis, the infestation level of guava by *B. dorsalis* and *B. zonata* was not significantly different ($P > |t|$ 0.1794).

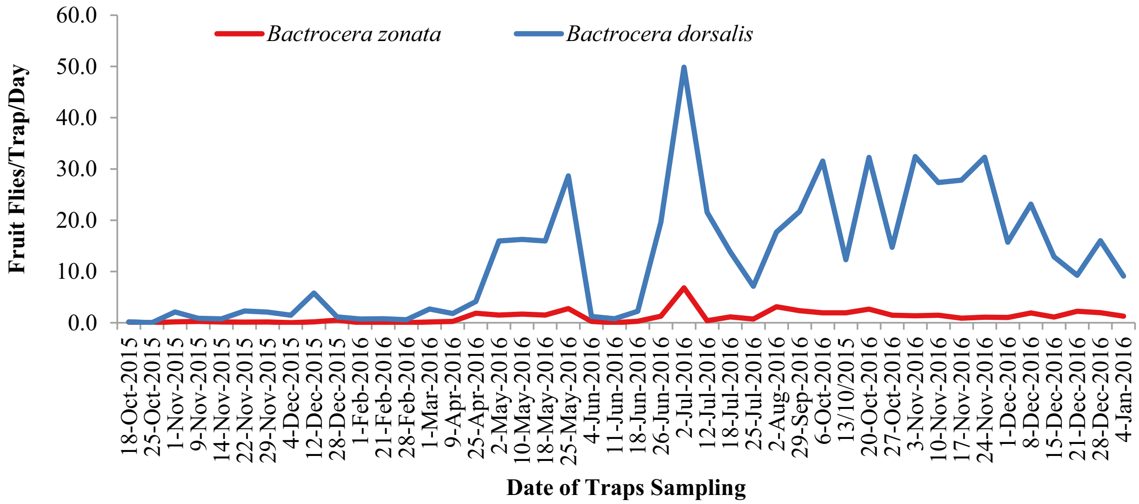

Fig. 3 Mean No of *B. zonata* and *B. dorsalis* / Trap/Day at G. Elfilsite using Torula yeast food bait attractant (18thNov 2015 to 28thDec July 2016)

3.5 Longevity and survival percentages of developmental stages of *B. zonata* and *B. dorsalis*

As presented in Table 1, it appears that, the two species are differ in their developmental period of different stages. Eggs of *B. zonata* required about 1.3 days more days than *B. dorsalis* (2.8 ± 0.2, 1.5 ± 0.3) to develop into larval stage, but larvae of *B. zonata* developed into pupae in 4.6and 5.9 fewer days than *B. dorsalis* (6.9 ± 0.3 versus 11.5 ± 1.2 days) and developed from pupae to adults faster (9.1 ± 1.1, 15 ± 0.3 days). The whole period of developmental stages of *B. zonata* was 18.8 days while that of *B. dorsalis* was 28 days with total difference 9.2 days between the two species. Survival percentages of eggs to larvae(82.9 ± 12.8 versus 75.5 ± 6.9%), larvae to pupae(90.2 ± 3.26 versus 46.4 ± 3.3%) and pupae to adults(85.5 ± 14.4 versus 62.6 ± 5.2%) of *B. zonata* were higher than that of *B. dorsalis* (Table 1).

4 Discussion

Monitoring of fruit flies is considered as an important strategy to determine species composition and to know the temporal and spatial distribution of various fruit fly species. Studies of population dynamics and seasonality of the pests help very much in identifying high population times and zones, facilitating early detection of new species and evaluate the efficiency of applied control measures [10]. Various fruit flies are attracted to pheromones, pheromone precursors, parapheromones and protein baits [3, 19–22].

According to the results of mass trapping campaigns conducted by Plant Protection Directorate in Sudan generally and in Gezira State particularly, *B. dorsalis* used to be the most abundant species since 2005 and the years before the arrival of *B. zonata* to the country in 2012 [23]. The current study revealed that, large population of *B. zonata* was trapped to Torula yeast at Fadasi site (99.3%) with high level of infestation of guava by the same species ranged from 200 to 750 fruit flies/kg of fruits during all the study period which suggests that *B. Zonata* has competitively displaced *B. dorsalis* from guava fruits In this study, the population of *B. zonata* peaked two times in July 2015 and December 2016 at both study sites regardless the number of fruit flies per trap per day for each site which was higher at Fadasi site compared to G. Elfil.

The results of seasonality of peach fruit fly is similar as that reported by [23] and as that reported in Pakistan by [24] which indicated, the activity of adults of *B. zonata* throughout the year in the coastal areas.

The increase of population of *B. dorsalis* in May, July and December of 2016 at G. Elfil and its peak in both sites in September to December 2016 Is similar trend was reported in Khartoum, Kassala and South Kordofan [8]. According to [25] in similar studies regarding the infestation levels in Egypt, fruit samplings of mango have recovered significantly more

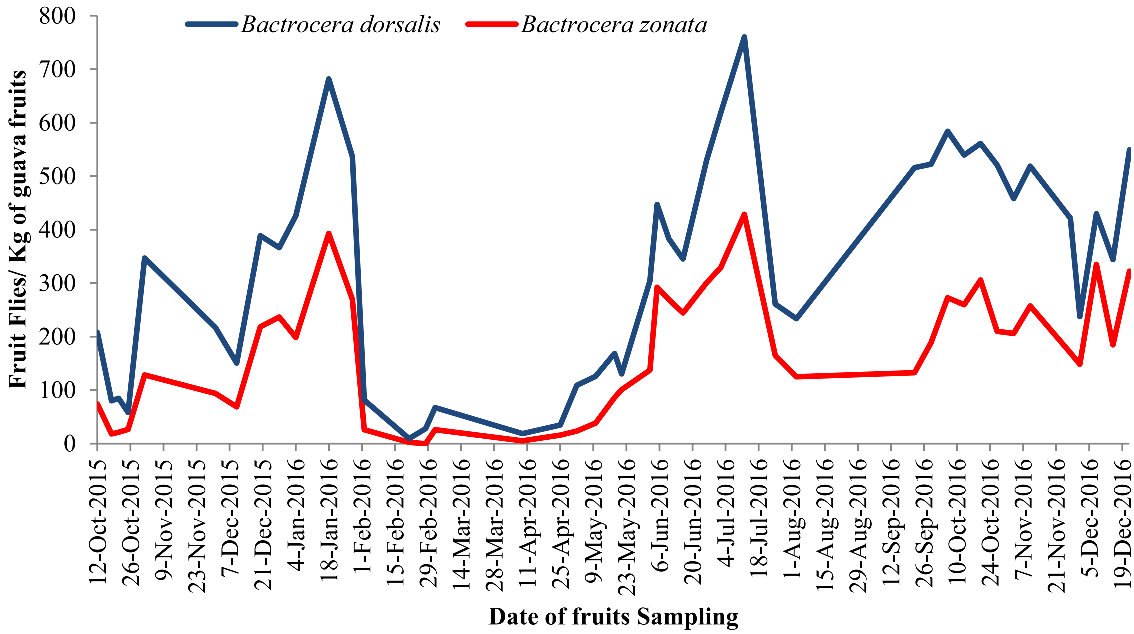

Fig. 4 Infestation Levels of guava fruits (Fruit fly/Kg of fruits) by *B. zonata* and *B. dorsalis* at G. Elfil site (12th Oct 2015 to 20th Dec 2016)

Table 1 Longevity (days; mean ± standard error) and survival (%; mean ± standard error) of developmental stages of *B. zonata* and *B. dorsalis* at 25 ± 1 °C and 60 ± 5RH

Developmental stage	Longevity		Survival	
	B. zonata	*B. dorsalis*	*B. zonata*	*B. dorsalis*
Egg	2.8 ± 0.2	1.5 ± 0.3	82.9 ± 12.8	75.5 ± 6.9
Larva	6.9 ± 0.3	11.5 ± 1.2	90.2 ± 3.3	46.4 ± 3.3
pupa	9.1 ± 1.1	15 ± 0.3	85.5 ± 14.4	62.6 ± 5.2

B. zonata than medfly adults which is comparable to the current study. Same infestation level by *B. dorsalis* in the current study (70–100%) to guava fruit was reported by [26] in the River Nile and Northern State, Sudan.

Competitive displacement between species of fruit flies and/or within other organisms has been reported by [27]. -*B. dorsalis* has been reported as the dominant fruit fly (88%) after 4 years of invasion and has completely displaced fruit flies from mango [28]. Also [29] reported that, under appropriate conditions, *B. dorsalis* and *B. correcta* showed a distinct advantage in competition for oviposition and noticeably suppressed *C. capitata*.

According to the trapping data of both species at G. Elfil site, the process of displacement of *B. dorsalis* with *B. zonata* was not happened (80% for *B. dorsalis* and 8% for *B. zonata* from the total trapped fruit flies which might be attributed to the presence of mango the most preferred fruits to *B. dorsalis* and also cultivation of other cucurbits. While In the same site the mean of the level of the infestation for *B. zonata* and *B. dorsalis* was comparably similar (167.2 and 156.6 Flies/Kg), respectively which expected to be changed to the benefit of *B. zonata* due to the time elapse as shown from other *Bactrocera* species introduced into Africa [30–32]. Among insects, the invasive species were reported to affect harmfully the native species through exploitative and interference competition [30, 33, 34]. In exploitative competition, mixed fruit infestations can result in inter-specific competition with native fruit fly species leading to shifts to other fruits or niche portioning.

It was very clear in this study that, *B. zonata* had shorter immature developmental period than *B. dorsalis* that may give *B. zonata* the advantage to increase its population more quickly than *B. dorsalis* per year. Also, percentage survival for each stage of *B. zonata* in guava is higher than *B. dorsalis*. Shorter life cycle and higher survival level of different stages may be the main factors that governed possible displacement of *B. dorsalis* by *B. zonata*. These findings are in accordance with studies that confirmed those factors in addition to fecundity, food consumption, aggressive behavior to land on the fruits and also the host marking pheromones where many species keep away from resources that are chemically marked or have already been demoralized [34] and. In other hand [35]reported that, the dominance of *B. invadens/dorsalis* to *C. cosyra* on mango in many parts of Africa can be attributed to pre-emption of resources and temperature.

5 Conclusion

Peach fruit fly was found all the year around infesting guava fruits and were more abundant to the oriental fruit fly in the guava ecosystem in Fadasi site. Possibilities of distribution and dominance of the *B. zonata* to all the country and bordering countries is highly expected with the elapse of the time [36], for that environmentally sound management program should be adopted in order to reduce the havoc anticipated by this pest.

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Author contribution Mohmmed E. E. Mahmoud, Mohamedazim I. Bashir and Rehab conduct the study Samira, Fathiya and Ekesi obtained the fund Abdel Gadir and Mohammed E. E. Mahmoud conduct statistical analysis and wrote the draft Samira, Fathiya and Ekesi revised the draft.

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Data availability Data are avilabe and will be provided by corresponding author upon request.

Declarations

Competing interests The authors declare no competing interests.

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