Biology, Ecology and Diversity

Biology and fertility life table of *Bactrocera carambolae* on grape and acerola

Joel Pasinato [ID][a],*, Luiza Rodrigues Redaelli[a], Marcos Botton[b], Cristiane Ramos de Jesus-Barros[c]

[a] *Universidade Federal do Rio Grande do Sul, Pós-Graduação em Fitotecnia, Departamento de Fitossanidade, Porto Alegre, RS, Brazil*
[b] *Embrapa Uva e Vinho, Bento Gonçalves, RS, Brazil*
[c] *Embrapa Amapá, Macapá, AP, Brazil*

A B S T R A C T

Bactrocera carambolae Drew & Hancock (Diptera: Tephritidae), native of Southeast Asia, is present in Brazil but restricted to Amapá, Pará and Roraima, where it has quarantine pest status. The possible dispersion to other fruit producing regions of Brazil could cause damages, including for exportation, due to quarantine restrictions imposed by fruit importing countries. The objective of this work was to describe the biological parameters and calculate the fertility life table of *B. carambolae* on grape (*Vitis vinifera* L.) and acerola (*Malpighia emarginata* DC.). The experiment was conducted in the laboratory under controlled conditions. The mean number of punctures and the mean number of eggs per female on grapes were 1.48 ± 0.05 and 9.87 ± 0.36, respectively. The mean number puparia per fruit was 0.1 ± 0.02 (grape) and 0.5 ± 0.10 (acerola). The pupal viability was 82.4% (grape) and 70.6% (acerola). The mean time $\pm$ SE of one generation, in days, was 25.8 ± 1.10 (grape) and 19.7 ± 0.21 (acerola). The mean fecundity was 1663.8 ± 501.01 (grape) and 206.9 ± 26.21 (acerola) with eggs viability of 5.6% (grape) and 12.5% (acerola). The mean longevity, in days, was 77.3 ± 12.13 on grape and 82.4 ± 4.24 on acerola. The study found that *B. carambolae* completes its biological cycle on grape and on acerola leaving offspring.

Introduction

The carambola fruit fly, *Bactrocera carambolae* Drew & Hancock (Diptera: Tephritidae), native to Southeast Asia, has been present in South America since 1975 (Malavasi and Zucchi, 2000; Silva et al., 2011). In Brazil, this fruit fly was recorded for the first time in 1996 and is restricted to the states of Amapá, Pará and Roraima (Godoy et al., 2011; Brazil, 2013; Morais et al., 2016). It has status of quarantine pest and is under official control of the Brazilian Ministry of Agriculture (MAPA) through the National Program for the Eradication of Carambola Fruit Fly (PNEMC) (Brazil, 2013). This fly is one of the most important pests in fruit production, especially as it is considered the main phytosanitary barrier for exports (Silva et al., 2005; Ferreira and Rangel, 2015).

The carambola fruit fly is a polyphagous species. In Brazil, it has been registered in 21 host fruits from nine families: *Anacardium occidentale* L. (Anacardiaceae), *Averrhoa carambola* L. (Oxalidaceae), *Byrsonima crassifólia* (L.) Kunth (Malpighiaceae), *Capsicum chinense* Jacq. (Solanaceae), *Citrus aurantium* L. (Rutaceae), *Citrus reticu-*

lata Blanco (Rutaceae), *Chrysobalanus icaco* L. (Chrysobalanaceae), *Eugenia stipitata* McVaugh (Myrtaceae), *Eugenia uniflora* L. (Myrtaceae), *Licania* sp. (Chrysobalanaceae), *Malpighia emarginata* Sessé & Moc. Ex. DC. (Malpighiaceae), *Mangifera indica* L. (Anacardiaceae), *Manilkara zapota* (L.) P. Royen (Sapotaceae), *Pouteria caimito* (Ruiz & Pav.) Radlk. (Sapotaceae), *Pouteria macrophylla* (Lam.) Eyma (Sapotaceae), *Psidium guajava* L. (Myrtaceae), *Psidium guineense* Swartz (Myrtaceae), *Rollinia mucosa* (Jacq.) Baill. (Annonaceae), *Spondias mombin* L. (Anacardiaceae), *Syzygium cumini* (L.) Skeels (Myrtaceae) and *Syzygium malaccense* (L.) Merr. & L. M. Perry (Myrtaceae) (Adaime et al., 2016). Thus, its possible dispersion to other regions of the country could jeopardize fruit production, depending on its ability to multiply in different crops (Marchioro, 2016; Pessoa et al., 2016; Jesus-Barros et al., 2017a).

Brazil is the third largest fruit producer in the world, being the fruit farming a major sector in Brazilian agribusiness (SEBRAE, 2015). Southern and northeastern Brazil are the most important poles of fruit production, especially the latter, which due to modern irrigation systems coupled with high temperatures throughout the year allow continuous production (Bustamante, 2009; Pederiva et al., 2015). In Brazil, one of these fruits is the grape, *Vitis vinifera* L. (Vitaceae), which is widely cultivated in northeastern and southern regions. Recently the world market was become interested in

fruits of *M. emarginata*, common named as acerola, Barbados-cherry or West Indian-cherry, which growns in northern and northeastern Brazil due to high vitamin C content (Calgaro and Braga, 2012; Pederiva et al., 2015).

In view of the importance of *B. carambolae* for national fruit growing and the lack of knowledge about its biological cycle, biological studies on its different hosts and even potential hosts are fundamental for risk prediction models of pest dispersal (Marchioro, 2016). Therefore, this work aimed to describe the biology of *B. carambolae* on the potential host, grape, and on the natural host, acerola, as well as calculate parameters of the fertility life table.

Material and methods

Rearing of the carambola fruit fly

The artificial rearing of the *B. carambolae* was established in 2013 and maintained in the Laboratory of Plant Protection at Embrapa Amapá, in Macapá, Amapá, Brazil. The larvae were kept under controlled condition chamber ($28 \pm 1°$, $80 \pm 10\%$ RH, without photophase) and fed an artificial diet based on sugarcane bagasse. The eggs were collected through artificial oviposition substrate. The diet was provided in Petri dishes (15×2.5 cm), where the eggs were deposited on a layer of moistened filter paper (4×6 cm). Dishes with diet and eggs were placed on plastic trays ($38 \times 53 \times 8$ cm) containing approximately 1.5 cm of fine vermiculite in the bottom for the larvae to pupate. The puparia were kept in plastic pots (500 mL) containing vermiculite in the bottom, in the incubator chamber ($26 \pm 1°$C, 12 h photophase). The adults were kept under controlled condition chamber ($27 \pm 1°$C; $70 \pm 10\%$ RH; 12 h photophase), in cages made from a transparent plastic box ($53 \times 37 \times 35$ cm), about 150 pairs per cage. They received food containing protein (Bionis® YE MF) and refined sugar in the proportion of 1:3 and water (Bariani et al., 2016).

Biology of carambola fruit fly on grape and acerola

The experiments were conducted from October 2016 to May 2017, with insects originating from the rearing. The adults used in the experiments with the grape cv. Itália and the acerola var. Junko were the sixth and the seventh generation reared in the laboratory, respectively.

The grapes used came from the São Francisco valley (Petrolina, Pernambuco, Brazil), whose insecticide applications ended 60 days before harvest and were collected at the harvest point. A sample of 20 berries was separated. They were measured, weighed, and the soluble solids (°Brix) were quantified using a digital refractometer (Hanna model – HI 96801) with the mean values recorded of 2.14 ± 0.03 cm, 0.008 ± 0.0003 g, and 15.1 ± 0.61 °Brix, respectively. The grapes were first offered approximately seven days after harvesting.

Six groups of 20 couples from one of the sexually mature breeding cages (20–28 days old) were separated into plastic jars ($21 \times 14 \times 12$ cm), with the same food used during rearing and water. For each group, ten berries of *V. vinifera* were offered, so that the fruit flies acquired a previous contact with this oviposition substrate (experiment), for a period of 24 h. Before being offered to the flies, the grapes were inspected to ensure the absence of oviposition punctures from the field and remained immersed in hypochlorite solution at 0.005% for 1 h, according to Menezes and Assis (2004), then washed and dried. After this period, ten grapes were offered daily for nine days to each group of couples, for a period of three and a half hours (11 AM to 2:30 PM), for a total sample of 540 berries. Soon after exposure, all berries were observed

under binocular stereomicroscope, to record the oviposition punctures, which were marked with a ballpoint pen. Subsequently, each berry was individually wrapped in a plastic pot (200 mL) containing a 0.5 cm thin-layer of vermiculite (type B) sterilized in the bottom and kept in an air-conditioned room ($28 \pm 1°$C; $80 \pm 10\%$ RH; without photophase).

Five days after exposure, a sample of 270 berries, five of each exposed set, were opened to count the number of viable and unviable eggs. The remaining 270 berries remained in the pots with vermiculite in the same chamber until the thirtieth day and were examined daily for larvae and/or puparia. Each puparium was weighed in a precision scale (Adventurer™, model – AR3130-3L0) and placed individually in flat-bottom glass tubes (8.5×1.5 cm), containing sterilized vermiculite and moistened filter paper, and closed with parafilm (Parafilm M®). The flasks with puparia were kept in an incubator ($26 \pm 1°$C; 12 h photophase) until emergence.

The puparia were observed daily to record the emergence, sex the percent of deformed adults. Couples were formed with adults without deformation and separated into plastic containers ($21 \times 14 \times 12$ cm), receiving water and the same diet used for rearing. For each couple, beginning the seventh day of life, an artificial oviposition substrate was offered according to Bariani et al. (2016) and a mixture of water and grape pulp of the same cultivar was placed inside. Each day, the substrates were replaced and the eggs counted. Each day, 20 eggs (or all the egg when there was less than twenty) were placed on sponge fabric moistened with distilled water and kept in an incubator ($26 \pm 1°$C; 12 h photophase) for hatching. This procedure was repeated throughout the oviposition period. The eggs were evaluated daily for six days by recording the number of larvae each day. The couples were kept to death.

The variables recorded were the number of punctures, total eggs, viable eggs and puparia, puparium weight, duration of egg–pupae, pupa, and egg–adult phases, sex ratio, longevity, fecundity, fertility, and length of pre oviposition, oviposition and post oviposition periods. The acerolas came from an organic orchard located in the rural area of Macapá, Amapá, Brazil. The fruits, about 0.5 cm in diameter, two to three days after flowering, were protected by bags made with voile type fabric. At the beginning of maturation (when the color of the pericarp turned from green to yellow), the fruits were harvested every two days and taken to the laboratory. A sample of 20 fruits was separated. Then they were measured, weighed, and the soluble solids (°Brix) quantified, using a digital refractometer (Hanna, model – HI 96801), and the mean values recorded were 2.5 ± 0.03 cm; 0.008 ± 0.0002 g; and 6.8 ± 0.09 °Brix, respectively.

The method used to disinfect, infest, and evaluate acerola was the same as the grapes. For acerola, the punctures and the number of eggs deposited could not be recorded, because the color and consistency of the pulp made it impossible reliably evaluate. Therefore, the evaluations of this fruit were carried out beginning in the pupa stage.

Statistical analysis

Averages, standard errors, and percentages of viability were calculated for each evaluated aspect. The averages were submitted to the homoscedasticity test and, according to the result, were compared by ANOVA or Kruskal–Wallis, at a significance level of 5%, using the program Bioestat® 5.0 (Ayres et al., 2007). Fertility life table parameters were calculated according to Silveira Neto et al. (1995), determining: net reproduction rate (Ro); interval between generations (r_m); and finite rate of increase (λ). Survival was calculated using Kaplan–Meier survival curves by program IBM SPSS Statistics 23 (IBM, 2013).

Table 1
Mean duration (± Standard Error) (days) and range (Variation Interval) of the egg–pupal, pupal, and egg–adult periods of *Bactrocera carambolae* maintained on grapes (*Vitis vinifera*) and acerola (*Malpighia emarginata*) in laboratory (26 ± 2 °C; 60 ± 10% Relative Humidity; photophase 12 h) (*N* = number of insects evaluated).

Period	Grape			Acerola		
	N	Mean (± Standard Error)	Variation Interval	*N*	Mean (± Standard Error)	Variation Interval
Egg–pupal	17	10.6 ± 0.29a[a]	9–14	281	9.2 ± 0.17b	6–16
Pupal	14	14.7 ± 1.27a	6–24	281	9.5 ± 0.17b	3–17
Egg–adult	14	25.8 ± 1.10a	17–35	317	19.7 ± 0.21b	16–40

[a] Means followed by different letters in the lines differ by Dunn test (*p* < 0.05).

Table 2
Mean duration (± Standard Error) of pre oviposition, oviposition, and post oviposition periods (days), mean longevity (± Standard Error) (days), and respective range of variability (Variation Interval) of mated *Bactrocera carambolae* adults maintained on grapes (*Vitis vinifera*) and acerola (*Malpighia emarginata*) in laboratory (26 ± 2 °C; 60 ± 10% Relative Humidity; photophase 12 h) (*N* = number of insects evaluated).

Parameter	Grape			Acerola		
	N	Mean (± Standard Error)	Variation Interval	*N*	Mean (± Standard Error)	Variation Interval
Period (days)						
Pre oviposition	5	14.8 ± 0.80[a]	13–17	62	17.6 ± 1.38[a]	10–92
Oviposition	5	46.8 ± 14.28[a]	6–87	61	60.3 ± 4.87[a]	1–132
Post oviposition	4	18.8 ± 7.75[a]	5–41	59	46.7 ± 6.25[a]	1–158
Longevity (days)						
Females	5	70.8 ± 12.16[a]	23–89	76	88.1 ± 5.81[a]	1–188
Males	5	83.8 ± 22.20[a]	2–127	69	76.2 ± 6.16[a]	2–200
Total	10	77.3 ± 12.13[a]	2–127	145	82.4 ± 4.24[a]	1–200

[a] Non significant difference between grape and acerola for the parameters evaluated by the Tukey or Dunn test (*p* > 0.05).

Results

Punctures were observed in 99% of the grapes offered to *B. carambolae* couples over nine days. The mean number of punctures per female was 1.48 ± 0.05 and did not differ between days (*F* = 2.1093; df = 8; *p* = 0.0542). The mean number of eggs per female in grapes was 9.87 ± 0.36. Each puncture contained, on average, 7.3 ± 0.22 eggs and in 15% of them had between one and three eggs.

The mean viable eggs per grape 0.4 ± 0.06 was extremely low, because from a total of 10,658 eggs counted, only 1142 were viable (10.7%). Despite the high number of eggs found in the grapes, mean puparia per grape (0.1 ± 0.02) was low, with a minimum of zero and a maximum of four, indicating low viability (1.5%) for the larval phase. Of the 300 grapes observed, 95.3% contained no puparium formation and pupal viability was 82.4%.

The mean number of puparia per acerola was 0.5 ± 0.10 (minimum zero and maximum 16), which is higher than observed on grapes. Of the 540 acerolas evaluated, 80.4% contained puparia and the pupal viability was 70.6%.

The mean pupal weight of the insects kept on grapes (11 ± 0.7 mg) ranged from 3 to 14 mg and was higher (*H* = 8.3839; df = 1; *p* = 0.0038) than those from acerolas (8 ± 0.3 mg), which varied from 1 to 10 mg.

The mean duration of the egg–pupal period on grapes was higher (*H* = 12.4094; df = 1; *p* = 0.0004) than in acerolas. This also occurred for the pupal phase (*H* = 25.3680; df = 1; *p* < 0.0001) and egg–adult period (*H* = 27.7148; df = 1; *p* < 0.0001) (Table 1).

No difference was detected between *B. carambolae* females from grape and acerola fruits for the duration of pre oviposition periods (*H* = 0.1379; df = 1; *p* = 0.7103), oviposition (*H* = 0.6779; df = 1; *p* = 0.4099), and post oviposition (*H* = 0.6014; df = 1; *p* = 0.4380) (Table 2).

The first ovipositions of *B. carambolae* on grapes were verified between 13 and 18 days after the emergence and extended until the hundredth day (Fig. 1). Between the twentieth and seventieth days, the amount of eggs deposited showed a marked variation between days. In females that developed on acerola, the first postures occurred between the eighth and fourteenth day after the emergency; however, one female only began to oviposition on

day 92 of life and remained active until day 134 (Fig. 1). Between the eleventh and thirty-first day, the greatest number of eggs was deposited, which remained consistent throughout this period, but then decreased after. The mean number of eggs/female/day for grapes and acerola was 19.4 ± 1.78 and 1.4 ± 0.14, respectively. In both groups, females did not oviposition some days. However, the females deposited on one day up to 60 eggs on grape and 10 on acerola.

The mean total fecundity in females from grape was 1663.8 ± 501.02 eggs (minimum of 248 and maximum of 2641), whereas for the acerola, it was 206.9 ± 26.21 eggs. The viability of eggs originated from adults whose larvae developed on grapes and acerola was 5.6% and 12.5%, respectively.

The mean longevity of the fruit flies did not differ between male and female for those on grape, (*F* = 0.2638, df = 1, *p* = 0.6254) or acerola (*H* = 2.3847; df = 1; *p* = 0.1225). Adults maintained on grape had similar longevity to acerola (*H* = 0.2312; df = 1; *p* = 0.6307) (Table 2). The survival of the insects maintained on grape ranged from 2 to 127 days, whereas on acerola, the minimum was of 1 and the maximum 200 days (Fig. 2).

The interval between generations (IGM) or mean generation time for grape and acerola was 25.8 and 19.7 days, respectively. The other parameters of the fertility life table, such as net reproduction rate (Ro), intrinsic rate of increase (r_m), and finite ratio (λ) were higher for acerola (Table 3).

Discussion

The presence of oviposition punctures in berries of two grape cultivars (*V. vinifera* and *Vitis labrusca* L.) has already been reported for another Tephritidae, *Anastrepha fraterculus* (Wiedemann) (Diptera: Tephritidae) (Zart et al., 2010). The puncture injury produced by this species can cause deformation and fall of the berries (Zart et al., 2011). The present study found that female *B. carambolae* punctured the *V. vinifera* berries, demonstrating the potential of this species to use the grape as host and cause this same type of injury. The mean number of punctures per female fruit fly was less than that found in starfruit (*A. carambola* L.) (Oxalidaceae) (2.57 ± 0.27) by Jesus-Barros et al. (2017b). Considering
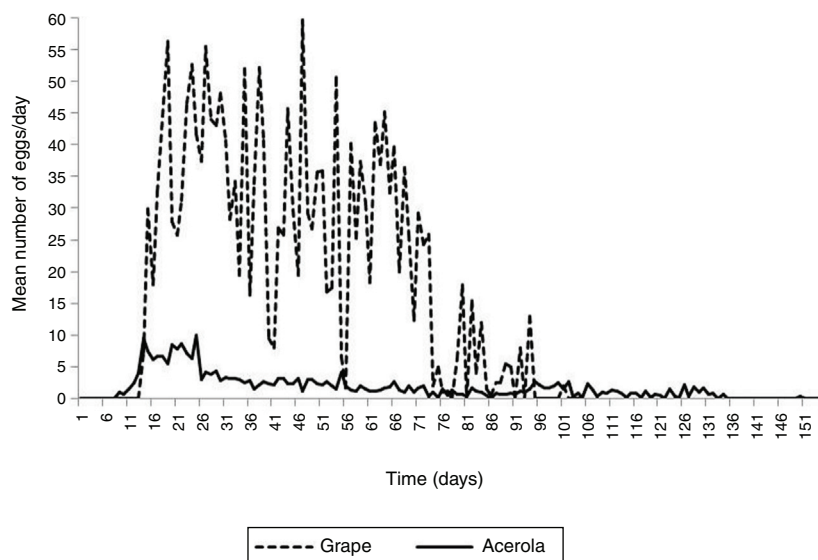
Fig. 1. Daily oviposition rhythm of *Bactrocera carambolae* on grapes (*Vitis vinifera*) and acerola (*Malpighia emarginata*) in laboratory (26 ± 2 °C; 60 ± 10% RH; photophase 12 h).
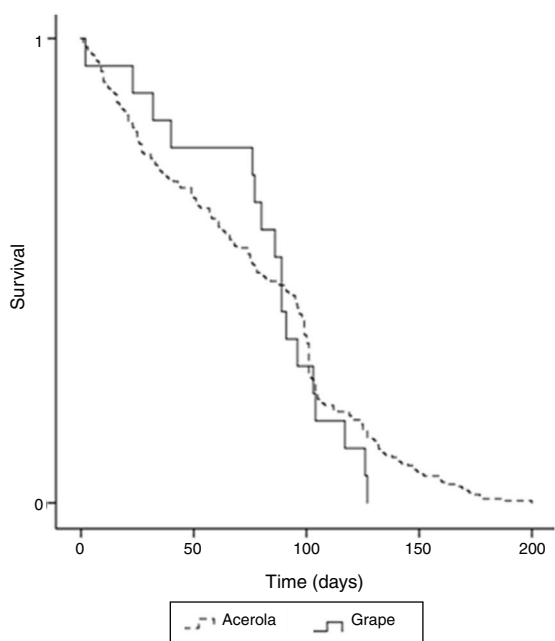

Fig. 2. Survival curves of *Bactrocera carambolae* adults grown on grapes (*Vitis vinifera*) and acerola (*Malpighia emarginata*) in laboratory (26 ± 2 °C; 60 ± 10% RH; photophase 12 h).

Table 3
Interval between generations (IGM) (days), net reproductive rate (Ro), intrinsic rate of population increase (r_m), and finite ratio of increase (λ) of *Bactrocera carambolae* maintained on grapes (*Vitis vinifera*) and acerola (*Malpighia emarginata*) in laboratory (26 ± 2 °C; 60 ± 10% Relative Humidity; photophase 12 h) (N = number of insects evaluated).

Host	IGM	Ro	r_m	λ
Grape	25.8	1.2	0.0007	1.01
Acerola	19.7	39.2	0.186	1.20

eggs were placed in groups and approximately 1–2 mm below the epicarp of grapes. It is important to note that in some punctures in the grape, no eggs were found, thus *B. carambolae*, even without infesting the grapes, can cause damage by injuring the epicarp with the ovipositor.

The mean number of eggs/female found in the grapes was lower than that observed by Jesus-Barros et al. (2017b) in starfruit (33.09 ± 4.49), also in laboratory. This difference may be related to the time each fruit was exposed, while each starfruit was offered for 48 h, the grapes remained with the flies for only three and a half hours.

The number of eggs deposited by *B. carambolae* per puncture in the grapes here was lower than recorded by Jesus-Barros et al. (2017b) and higher than Chua (1994), both in starfruit in laboratory. Thus, it seems that this is not related either to the species or the amount of host fruits. The size of the egg groups deposited by *B. carambolae* in starfruit in laboratory was not associated with the fact that the females had only one or several fruits available (Chua, 1994). In a starfruit orchard, naturally infested by *B. carambolae*, Chua and Khoo (1995) found a variable number of eggs/puncture, which the authors attributed to a strategy to avoid intraspecific competition and/or escape from natural enemies. Females of *B. dorsalis* responded to the increase in fruit supply, placing smaller groups in a larger number of hosts (Xu et al., 2012). Despite the large number of eggs deposited by *B. carambolae*, the viability was low; this result may be related to the type of food in which the larvae were reared, a diet with structural element from sugarcane bagasse and protein source from soy protein (Bariani et al., 2016). Another factor that may have also influenced viability is the inbreeding that occurs when many generations are kept in the laboratory, without the periodic introduction of wild individuals, in case the insects used were the sixth-generation laboratory reared.

that each starfruit was exposed to only one female fruit fly, the results suggest that the presence of many individuals (20) in the grapes may have generated competition and reduced the number of punctures per individual. The size of the fruit may also have interfered in the number of punctures, since grapes, although they were offered in a higher number (10), have a much smaller area available for oviposition/female than starfruit. The maturation stage of the starfruit when offered to the fruit flies was green and ripe-green while the grapes were already ripe, which may make them less attractive, a factor that may be responsible for the higher number of punctures/female found by Jesus-Barros et al. (2017b).

B. carambolae deposited eggs in the grapes in groups and just below the epicarp, which similar to that described for *A. fraterculus* by Paranhos (2008) and Godoy et al. (2011). In *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), Xu et al. (2012) also found that the

The reduced number of puparia formed in the grapes also shows the low viability of the larval phase, which may be because this fruit is not a natural host of *B. carambolae* and nutritionally adequate, along with the high intraspecific competition, as only 25% of the larvae in a grape reached the pupal stage. The maturation stage of the fruits may explain this low viability is since the grapes were already ripe when exposed to the flies, thus reducing the time in which they could providing adequate nutrients for larval development. Larval viability of *B. dorsalis*, on grapes, depended on this stage of ripeness (Chu and Tung, 1996). In *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), Krainacker et al. (1987) verified that the nutritional quality of the fruit is the main factor affecting larval performance. The larval development of *C. capitata* in kaki (*Diospyros kaki* L.) (Ebenaceae), apple (*Malus domestica* Borkheim) (Rosaceae), peach (*Pyrus communis* L.) (Rosaceae), and grape was compared and although grape has a high value of total proteins, it also had the highest amount of soluble acids and pH, which may affect the development of fruit flies with in the grape (Zanardi et al., 2011). The nutritional quality of the same fruit varies, so in high infestations, the ingestion of less nutritious tissues is more probable (Dukas et al., 2001).

The mean number of puparia formed in the acerolas exposed to the carambola fruit fly was greater than in the grapes. In fact, acerola has been reported as a host of carambola fruit fly, both in Suriname, by Sauers-Muller (2005), and in Brazil, by Adaime et al. (2016). Although the egg and larva stages presented low viability on grape, it was high in the pupal stage (82.4%), which was also observed on acerola (70.6%). These values are corroborated by those reported by Himawan et al. (2012), although they feed the larvae of *B. carambolae* with diets based on grains (92.1%) and tofu (83.2%).

The lower weight of the puparia obtained in acerola compared to grape can be explained by the greater number of these observed per fruit, which caused the food resource to be divided by a larger number of larvae. Zart et al. (2010), maintaining *A. fraterculus* in *V. vinifera* grapes, obtained heavier pupae (15.1 ± 0.31 mg). Similar values were also detected for *Anastrepha* sp. in Myrtaceae fruits (Salles and Leonel, 1996). The latter authors mentioned that the heavier puparia were observed when the fruits had smaller number of puparia.

The duration of the egg–pupal, pupal, and egg–adult phases was significantly shorter for the insects that developed on acerola, a difference that may be due to the distinct nutritional quality between these two hosts. The acerolas may have provided adequate and sufficient resources for the larvae, thus allowing the biological cycle to be shorter, because the only difference between the two groups was the host fruit.

For the adult phase, the duration of the pre oviposition, oviposition, and post oviposition periods were similar for insects developed on grape or acerola. Females of *B. carambolae* from starfruit and maintained under the same laboratory conditions also had long oviposition periods (Jesus-Barros et al., 2017a). Female tephritids are sinovigenic, then need to eat food, especially protein, for oocyte maturation throughout their lives (Tsiropoulos, 1983; Zucoloto, 2000). Thus, the duration of the pre oviposition period observed for *B. carambolae* appears to be similar to other species of this group.

The oviposition pattern observed in present study is corroborated by Jesus-Barros et al. (2017a), in laboratory for this same tephritid species. These combined results affirm that the long period of oviposition of *B. carambolae* may exacerbate the damages it can cause in the field. In other tephritids, such as *A. fraterculus* also maintained in *V. vinifera* grape, Zart et al. (2010) found a shorter mean period of oviposition (20.70 ± 2.76 days), indicating less potential to cause damage, compared to the carambola fruit fly. For *C. capitata*, Zanardi et al. (2011) recorded oviposition periods longer than that of *A. fraterculus*, but shorter than observed for

B. carambolae. The duration of the oviposition period in tephritids seems to be an intrinsic characteristic of the species.

The average fecundity of *B. carambolae* that have grown into grapes followed the pattern reported for the species by Godoy et al. (2011) and Malavasi et al. (2013), which is to lay 1000 to 3000 eggs throughout her life in laboratory and, from 1200 to 1500 in the field. However, for the acerola group, mean values of fecundity were lower. For artificial oviposition substrates containing either grape or acerola pulp, the results suggest that grape is more attractive to *B. carambolae*. In Diptera, Broufas et al. (2009) stated that host quality affects oviposition dynamics and ovarian maturation. Oviposition in this group, itself stimulates egg maturation (Papaj, 2005). However, the viability, compared to that recorded for females fed on sugarcane bagasse diet, was superior in both hosts, indicating that these fruits are nutritionally superior.

Mean longevity did not differ between adults from both hosts. The extremely small number of adults evaluated from the grape ($n = 10$, five males and five females) may be responsible for this lack of detected significant difference. In the present study, the mean longevity adults of in acerola was 82.4 ± 4.24, with a minimum survival of 1 and maximum of 200 days; while in the grape, longevity was 77.3 ± 12.13, with a minimum of 2 and a maximum of 127 days (Fig. 2). Although done in laboratory, these results still suggest that the carambola fruit fly can survive for a long period of time, during which, in addition to causing damage, it can leave many offspring. Our results are corroborated by those of Jesus-Barros et al. (2017a) who recorded, for females of this species minimum survival of 15 and maximum of 150 days.

No adults with deformation were found in the group from the grape, perhaps due to the small number of insects that emerged. In acerola, 2.8% of adults were found with wing deformations, which may be associated with absence or a low level of hormones that control the process of ecdysis and metamorphosis. In addition, low humidity and nutritional deficiency can affect the emergence process (Gullan and Cranston, 2012). Himawan et al. (2012) also reported that good imago quality depends on the diet of the immature insect, because it needs to provide nutrients that ensure good nutrition. In the present study, the small percentage of deformation does not appear to be associated with the nutritional quality of the host.

The net reproduction rate (Ro), that is, the total number of female offspring produced per female throughout the breeding season, which reaches the next generation, for the insects that developed on grapes was 1.2. In acerola, the value was about 33 times higher (39.2), indicating that acerola is a more suitable host for *B. carambolae*. However, even with low Ro values, the grape allowed the species to multiply. For another species of the same genus, *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae), the Ro values observed by Yu-Bing and Hsin (2012) also varied according to host; in *Cucumis sativus* L. (Cucurbitaceae) it was 137.8; in *Luffa cylindrica* Mill (Cucurbitaceae) 172.3; and in the *Daucus carota* L. (Apiaceae) 46.8. On *V. vinifera* grapes, Zart et al. (2010) found a very similar value (1.71) for *A. fraterculus* as we did for *B. carambolae*, which indicates that grapes are not a good host for fruit flies.

The intrinsic rate of population increase (r_m) or the innate ability to increase in number was about 265 times lower for individuals kept in grape than for those who fed on acerola. This result indicates that acerola is indeed an important multiplier host for *B. carambolae* in North region of Brazil, corroborating that pointed out by Almeida et al. (2016).

The finite ratio of increase (λ) or the number of times the population multiplies in a unit time, on grape was 1.01, which was equal to that found by Zart et al. (2010) for *A. fraterculus* in the same type of grape. Yu-Bing and Hsin (2012), who feed *B. cucurbitae* larvae on *C. sativus* L. (Cucurbitaceae), *Lagenaria siceraria* (Molina) Standl.

(Cucurbitaceae), or *D. carota*, also found values between 1.07 and 1.15, which is similar to those of this study. This parameter does not appear to vary among the tephritid species even in different hosts.

This work was the first in Brazil to evaluate the biology of *B. carambolae* on grape and acerola. Although this species is not directly related to grape, as this fruit is not cultivated in its center of origin, the results indicate that the carambola fruit fly recognizes grape as an oviposition substrate. Although grape is not a good host, the large number of punctures recorded in the grapes indicate the possibility of extensive damage by this fruit fly to this crop. The few individuals who reached the adult stage in grape showed high fecundity and were long-lived, which are important aspects to consider when studying the potential of an insect to become a pest.

On the other hand, acerola is already reported to host this species. Our results demonstrated that this fruit was suitable for of *B. carambolae* development. Acerola could become a multiplier host increasing the probability for the population growth of this fruit fly, because acerola is cultivated in other regions of Brazil and has great commercial interest.

The study of Marchioro (2016) showed, based on the climatic factors, that the dispersion of *B. carambolae* to other regions of the country is possible. The results of the present work verify that grapes and acerola are suitable for the development of this species. Therefore, measures to prevent the dispersion of the carambola fruit fly to other areas is important due to the economic importance of fruit crops in Brazil, both for the internal and external markets, along with the imposed quarantine barriers.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

References

Adaime, R., Jesus-Barros, C.R., Bariani, A., Lima, A.L., Cruz, K.R., Carvalho, J.P., 2016. Novos registros de hospedeiros da mosca-da-carambola (*Bactrocera carambolae*) no estado do Amapá, Brasil. Embrapa Amapá, Comunicado Técnico 146, Macapá.

Almeida, R.R., Cruz, K.R., Sousa, M.S.M., Costa-Neto, S.V., Jesus-Barros, C.R., Lima, A.L., Adaime, R., 2016. Frugivorous flies (Diptera: Tephritidae, Lonchaeidae) associated with fruit production on Ilha de Santana, Brazilian Amazon. Fla. Entomol. 99, 426–436.

Ayres, M., Ayres-Junior, M., Ayres, D.L., Santos, A.A.S., 2007. BioEstat 5.0: aplicações estatísticas nas áreas das ciências biológicas e médicas. Sociedade Civil Mamirauá, Belém.

Bariani, A., Jesus-Barros, C.R., Carvalho, J.P., Mota-Junior, L.O., Nascimento, P.R., Cruz, K.R., Facundes, V.S., 2016. Técnicas para criação da mosca-da-carambola (*Bactrocera carambolae* Drew & Hancock) em laboratório para pesquisa científica. Embrapa Amapá, Documento 97, Macapá.

Brasil. Ministério da Agricultura, Pecuária e Abastecimento. Instrução Normativa n° 59, de 18 de dezembro de 2013. Diário Oficial [da] República Federativa do Brasil, Brasília, DF, 24 dez. 2013. Seção 1. Available at: http://sistemasweb.agricultura.gov.br/cefiti/leg/IN59-2013.pdf (accessed 05.02.18).

Broufas, G.D., Pappas, M.L., Koveos, D.S., 2009. Effects of relative humidity on longevity, ovarian maturation, and egg production in the olive fruit fly (Diptera: Tephritidae). Ann. Entomol. Soc. Am. 102, 70–75.

Bustamante, P.M.A.C., 2009. A fruticultura no Brasil e no Vale do São Francisco: vantagens e desafios. Rev. Eletrôn. Nordeste 40, 153–171.

Calgaro, M., Braga, M.B., 2012. A cultura da acerola. Embrapa Semiárido, Brasília.

Chu, Y.I., Tung, C.H., 1996. The laboratory observations on the attack of oriental fruit fly *Bactrocera dorsalis* (Hendel) on grapes. Plant Prot. Bull. 38, 49–57.

Chua, T.C., 1994. Egg batch size of the carambola fruit fly *Bactrocera* sp. (Malaysian A) (Diptera: Tephritidae). Pertanika J. Trop. Agric. Sci. 17, 107–109.

Chua, T.H., Khoo, S.G., 1995. Variations in carambola infestation rates by *Bactrocera carambolae* Drew and Hancock (Diptera: Tephritidae) with fruit availability in a carambola orchard. Popul. Ecol. 37, 151–157.

Dukas, R., Prokopy, R.J., Duan, J.J., 2001. Effects of larval competition on survival and growth in Mediterranean fruit flies. Ecol. Entomol. 26, 587–593.

Ferreira, M.E., Rangel, P.H.N., 2015. Melhoramento genético preventivo: obtenção de estoques genéticos resistentes a pragas quarentenárias de alto risco para a agricultura brasileira. In: Sugayama, R.L., Silva, M.L. da, Silva, S.X. de B., Ribeiro, L.C., Rangel, L.E.P. (Eds.), Defesa vegetal: fundamentos, ferramentas, políticas e perspectivas. Sociedade Brasileira de Defesa Agropecuária, Belo Horizonte, pp. 275–292.

Godoy, M.J.S., Pacheco, W.S.P., Portal, R.R., Pires-Filho, J.M., Moraes, L.M.M., 2011. Programa Nacional de Erradicação da mosca-da-carambola. In: Silva, R.A., Lemos, W.P., Zucchi, R.A. (Eds.), Moscas-das-frutas na Amazônia brasileira: diversidade, hospedeiros e inimigos naturais. Embrapa Amapá, Macapá, pp. 135–172.

Gullan, P.J., Cranston, P.S., 2012. Os insetos: um resumo de entomologia. Roca, São Paulo.

Himawan, T., Karindah, S., Hendrawan, D., 2012. Growth and development of *Bactrocera carambolae* Drew & Handcock (Diptera: Tephritidae) on three artificial diets. J. Trop. Plant Prot. 1, 14–21.

IBM Corporation, 2013. IBM SPSS statistics for windows: versão 22.0, Armonk.

Jesus-Barros, C.R., Mota-Junior, L.O., Costa, A.S., Pasinato, J., Adaime, R., 2017a. Fecundidade e longevidade de *Bactrocera carambolae* Drew & Hancock (Diptera: Tephritidae). Biotemas 30, 7–13.

Jesus-Barros, C.R., Oliveira, W.S., Carvalho, J.P., Mota-Junior, L.O., Bariani, A., Lima, A.L., Adaime, R., 2017b. Tamanho das posturas de *Bactrocera carambolae* Drew & Hancock (Diptera: Tephritidae) em carambola (*Averrhoa carambola*). Entomotropica (in press).

Krainacker, D.A., Carey, J.R., Vargas, R.I., 1987. Effect of larval host on life history traits of the Mediterranean fruit fly, *Ceratitis capitata*. Oecologia 73, 583–590.

Malavasi, A., Midgarden, D., Meyer, M., 2013. *Bactrocera* species that pose a threat to Florida: *B. carambolae* and *B. invadens*. In: Peña, J. (Ed.), Potential Invasive Pests of Agricultural Crops. CABI, Homestead, http://dx.doi.org/10.1079/9781845938291.0000.

Malavasi, A., Zucchi, R.A., 2000. Moscas-das-frutas de importância econômica no Brasil: conhecimento básico e aplicado. Holos, Ribeirão Preto.

Marchioro, C.A., 2016. Global potential distribution of *Bactrocera carambolae* and the risks for fruit production in Brazil. PLOS ONE 11, e0166142.

Menezes, M., Assis, S.M.P., 2004. Guia prático para fungos fitopatogênicos. Imprensa Universitária UFRPE, Recife.

Morais, E.G.F., Jesus-Barros, C.R., Adaime, R., Lima, A.L., Navia, D., 2016. Pragas de expressão quarentenária na Amazônia. In: Silva, N.M., Adaime, R., Zucchi, R.A. (Eds.), Pragas agrícolas e florestais na Amazônia. Embrapa Amazônia Oriental, Brasília, pp. 528–533.

Papaj, D.R., 2005. Ovarian dynamics in relation to host quality in the Walnut-infesting fly, *Rhagoletis juglandis*. Funct. Ecol. 19, 396–404.

Paranhos, B.J.,2008. Mosca-das-frutas que oferecem risco a fruticultura brasileira. In: Simpósio Internacional de Vitivinicultura, 2008, Petrolina. Anais. . . Embrapa Semiárido, Petrolina.

Pederiva, C.J., Freitas, T.G., Bueno, M.C., Amaral, A.S., Lima, C.Z.,2015. Produção de frutíferas na região sul do Brasil. In: Simpósio de Agronomia e Tecnologia de Alimentos, 2, 2015, Itapiranga. Anais. . . Faculdades de Itapiranga, Itapiranga.

Pessoa, M.P.C.Y., Marinho-Prado, J.S., Mingoti, R., Lovisi-Filho, E., Silva, A.S., Moura, M.S.B., Silva-Filho, P.P., Sá, L.A.N., Prado, S.S., Spadotto, C.A., Farias, A.R., 2016. Estimativa de potencial adaptação de *Bactrocera carambolae* Drew & Hancock (Praga Quarentenária A2): estudo de caso para dois perímetros irrigados do vale do Rio São Francisco. Embrapa Gestão Territorial, Nota Técnico-Científica, Campinas, http://dx.doi.org/10.13140/RG.2.2.26774.14401.

Salles, L.A.B., Leonel, M.A.H., 1996. Influência do hospedeiro no desenvolvimento larval e pupal de *Anastrepha fraterculus* (Wied.) (Diptera: Tephritidae). An. Soc. Entomol. Bras. 25, 373–375.

Sauers-Muller, A.V., 2005. Host plants of the carambola fruit fly, *Bactrocera carambolae* Drew & Hancock (Diptera: Tephritidae), in Suriname, South America. Neotrop. Entomol. 34, 203–214.

SEBRAE – Serviço Brasileiro de Apoio a Micro e Pequenas Empresas, 2015. Mercado de fruticultura: panorama do setor no Brasil, Brasília.

Silva, R.A., Lemos, W.P., Zucchi, R.A., 2011. Moscas-das-frutas na Amazônia brasileira diversidade, hospedeiros e inimigos naturais. Embrapa Amapá, Amapá.

Silva, R.A., Jordão, A.L., Sá, L.A.N., Oliveira, M.R.V., 2005. Ocorrência da mosca-da-carambola no estado do Amapá. Rev. Cient. Eletrôn. Agron. 4, 1–6.

Silveira Neto, S., Monteiro, R.C., Zucchi, R.A., Moraes, R.C.B., 1995. Uso da análise faunística de insetos na avaliação do impacto ambiental. Sci. Agric. 52, 9–15.

Tsiropoulos, G.J., 1983. The importance of dietary aminoacids on the reproduction and longevity of adult *Dacus oleae* (Gmelin) (Diptera: Tephritidae). Arch. Int. Physiol. Biochim. 91, 159–164.

Xu, L., Zhou, C., Xiao, Y., Zhang, P., Tang, Y., Xu, Y., 2012. Insect oviposition plasticity in response to host availability: the case of the tephritid fruit fly *Bactrocera dorsalis*. Ecol. Entomol. 37, 446–452.

Yu-Bing, H., Hsin, C., 2012. Age-stage, two-sex life tables of *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae) with a discussion on the problem of applying female age-specific life tables to insect populations. Insect Sci. 19, 263–273.

Zanardi, O.Z., Nava, D.N., Botton, N., Grutzmacher, A.D., Machota-Junior, R., Bisognin, M., 2011. Desenvolvimento e reprodução da mosca-do-mediterrâneo em caquizeiro, macieira, pessegueiro e videira. Pesqui. Agropec. Bras. 46, 682–688.

Zart, M., Fernades, O.A., Botton, M., 2010. Biology and fertility life table of the South American fruit fly *Anastrepha fraterculus* on grape. Bul. Insectol. 63, 237–242.

Zart, M., Botton, M., Fernandes, O.A., 2011. Injurias causadas por mosca-das-frutas Sul-americana em cultivares de videira. Bragantia 70, 64–71.

Zucoloto, F.S., 2000. Nutrição e alimentação. In: Malavasi, A., Zucchi, R.A. (Eds.), Moscas-das-frutas de importância econômica no Brasil: conhecimento básico e aplicado. Holos, Ribeirão Preto, pp. 67–80.