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New findings on carambola fruit fly hosts in South America

José Victor Torres Alves Costa[1], Maria do Socorro Miranda de Sousa[2], Cristiane Ramos de Jesus[3], Miguel Francisco de Souza-Filho[4], Valmir Antonio Costa[4], Breno Marques da Silva e Silva[5], Jessica Paula Monteiro Oliveira[5], and Ricardo Adaime[3,]*

Abstract

Bactrocera carambolae Drew & Hancock (Diptera: Tephritidae), the carambola fruit fly, is a quarantine pest present in Brazil, restricted to the states of Amapá, Pará, and Roraima. Its dispersion to other regions of the country could cause serious socioeconomic damage. Fruits were collected from urban trees, residential backyards, and small orchards in rural and urban areas of the municipality of Oiapoque, Amapá, Brazil. A total of 240 samples (11,126 fruits; 288.8 kg) of 33 plant species (16 native and 17 introduced species) from 19 families were collected. *Bactrocera carambolae* was isolated from the fruits of 13 plant species. In addition, specimens of 8 *Anastrepha* species were collected in this study. Moreover, 5 parasitoid species (Hymenoptera; 3 Braconidae and 2 Figitidae species) associated with *Anastrepha* spp. were identified. Overall, this study adds 3 new records to the list of host plants for *B. carambolae* in Brazil (*Artocarpus heterophyllus* Lam.; Moraceae, *Passiflora quadrangularis* L.; Passifloraceae, and *Ziziphus mauritiana* Lam.; Rhamnaceae), two of them (*A. heterophyllus* and *P. quadrangularis*) new records for South America, and demonstrates new interactions between *Anastrepha* species and host plants in the extreme north of the state of Amapá. Notably, this is the first report of the figitid species, *Aganaspis nordlanderi* Wharton, in the state of Amapá.

Key Words: *Bactrocera carambolae*; ecology; pest; Amapá; Amazon

Resumo

Bactrocera carambolae Drew & Hancock (Diptera: Tephritidae), a mosca-da-carambola, é uma praga quarentenária presente no Brasil, restrita aos estados do Amapá, Pará e Roraima. Sua dispersão para outras regiões do país poderia causar sérios prejuízos socioeconômicos. Os frutos foram coletados em árvores urbanas, quintais residenciais e pequenos pomares nas áreas rurais e urbanas do município de Oiapoque, Amapá, Brasil. Um total de 240 amostras (11.126 frutos; 288,8 kg) de 33 espécies vegetais (16 nativas e 17 introduzidas) de 19 famílias foram coletadas. *Bactrocera carambolae* foi isolada dos frutos de 13 espécies vegetais. Além de *B. carambolae*, foram coletados neste estudo espécimes de 8 espécies de *Anastrepha*. Além disso, 5 espécies de parasitoides (Hymenoptera; 3 espécies de Braconidae e 2 de Figitidae) associadas a *Anastrepha* spp. foram identificadas. No geral, este estudo acrescenta 3 novos registros à lista de plantas hospedeiras de *B. carambolae* no Brasil (*Artocarpus heterophyllus* Lam.; Moraceae, *Passiflora quadrangularis* L.; Passifloraceae e *Ziziphus mauritiana* Lam.; Rhamnaceae), dois deles novos registros na América do Sul (*A. heterophyllus* e *P. quadrangularis*) e demonstra novas interações entre espécies de *Anastrepha* e plantas hospedeiras no extremo norte do estado do Amapá. Notavelmente, este é o primeiro relato da espécie de figitídeo *Aganaspis nordlanderi* Wharton no estado do Amapá.

Palavras-Chave: *Bactrocera carambolae*; ecologia; praga; Amapá; Amazônia

Fruit flies (Diptera: Tephritidae) are well-known phytophagous insect species that have been extensively studied in tropical regions because of the damage they cause to several economically important fruits (Aluja 1994; Araujo et al. 2018). Their larvae develop by feeding on the fruit pulp of various species, making the fruits unsuitable for sale, fresh consumption, and industrialization (Paranhos et al. 2004; Aluja & Mangan 2008). Furthermore, some flies may violate the phytosanitary barriers imposed by fresh fruit-importing countries that necessitate the absence of pests, thereby causing indirect damage and impacting fruit export (Malavasi 2000; Paranhos et al. 2004). Oliveira et al. (2013) revealed that the annual economic losses in agriculture caused by insects are estimated to be approximately US$12 billion, including US$1.14 billion associated with fruit production and $1.6 billion associated with the introduction of exotic species. Production losses, control costs, and marketing analyses estimate that fruit flies cause annual losses of approximately US$36 million (R$180 million) in Brazil (MAPA 2015; Nava et al. 2019).

In Brazil, *Anastrepha* is the most diverse fruit fly genus, with 128 recorded species (Zucchi & Moraes 2023) distributed across all Brazilian states, harming different host families (Malavasi et al. 2000). Seventy-

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eight species have been reported in the Brazilian Amazon, with the Amazonas and Amapá states having the highest numbers of species, 41 and 37, respectively (Adaime et al. 2023). In addition to *Anastrepha* species, 2 exotic species, *Bactrocera carambolae* Drew & Hancock, the carambola fruit fly, and *Ceratitis capitata* (Wiedemann), the Mediterranean fruit fly occur in the region (Costa et al. 2022).

Bactrocera carambolae is native to Southeast Asia and was first recorded in the municipality of Oiapoque (Amapá, Brazil) in 1996. It occurs in specific areas of Amapá, Pará, and Roraima states (MAPA 2018). It is a polyphagous species, with 26 host plant species registered in Brazil, affecting fruits of high economic relevance, such as citrus and mangoes (Adaime et al. 2016a; Belo et al. 2020). This pest is considered as the main phytosanitary barrier to the export of fruits produced in Brazil (Silva et al. 2004; Ferreira & Rangel 2015; Miranda & Adami 2015). *Ceratitis capitata*, is native to the African continent (White & Elson-Harris 1992) but currently is observed in various tropical, subtropical, and warm temperate areas around the world, causing significant damage to host plants (Silva et al. 1998; Malacrida et al. 2007; Malavasi 2009).

Recently, fruit fly studies have gained attention in the Brazilian Amazon, especially those scientists focusing on the diversity, geographic distribution, and identification of host plants (Deus et al. 2013; Almeida et al. 2016; Adaime et al. 2017). Moreover, the risk of multiplication and proliferation of these flies is high due to their ability to use different host fruit species. Therefore, it is crucial to identify and investigate the host plants of these insects and assess their infestations from fruit sampling (Almeida 2016). Frequent reports of *B. carambolae* hosts in Brazil reinforces the need to intensify field sampling to confirm new host species of economic interest as well as those widely reported in other countries. Additionally, it is crucial to carry out studies based on fruit sampling, to obtain information about the parasitoid species (Hymenoptera) that act in the natural biological control of fruit flies (Silva et al. 2011a).

Although various studies have investigated frugivorous flies in the Brazilian Amazon, some areas, such as the extreme north of the state of Amapá (Brazil) that includes the municipality of Oiapoque at the border with French Guiana, have not yet been studied (Adaime et al. 2017). It is necessary to investigate the fruit flies in Brazil as the transport of infested fruits is the main method of fruit fly dispersion in this region (Duarte & Malavasi 2000), with the Brazilian Amazon acting as the gateway for several agricultural and forestry pests, some of which are quarantined (Morais et al. 2016). Transportation through the Oiapoque River basin consists of formal land traffic and informal river traffic, and the goods are carried in small boats to the riverbank communities (Silva et al. 2019).

Adaime et al. (2017, 2018a) reported the significant risk of introducing *Anastrepha suspensa* (Loew), which has quarantine potential, in Brazil via the state of Amapá, especially due to the vehicle traffic over the bridge connecting the French and Brazilian territories. Insect dispersion can occur via the transport of fruits containing live larvae in international trade or passenger traffic. Natural movement is also an important means of dispersal for some *Anastrepha* species that can fly up to 135 km (Fletcher 1989).

Oiapoque is the original entry point for *B. carambolae* in Brazil (Silva et al. 1997; Silva et al. 2004; Godoy et al. 2011; Malavasi 2015), which supports the risk of introducing *A. suspensa*. As it is a border region, a more intensive fruit sampling effort is necessary to understand the dynamics among *B. carambolae*, other fruit fly species, and their associated parasitoids in Oiapoque. Therefore, in this study, we aimed to identify the fruit fly species, their host plants, and associated parasitoids in the municipality of Oiapoque in the extreme north of the state of Amapá, Brazil.

Materials and Methods

STUDY AREA

The study area covered the municipality of Oiapoque (Fig. 1) in the extreme north of the state of Amapá, Brazil. It is limited to the north by French Guiana and to the south by the municipalities of Calçoene, Serra do Navio, and Pedra Branca do Amapari. It is bordered by the Atlantic Ocean in the east and the municipality of Laranjal do Jari in the west (Neto & Lira 2022). It is 577.9 km away from the capital of Macapá via highway BR-156.

Oiapoque occupies a territorial area of 23,034.392 km², accounting for 16.17% of the total area of Amapá (142,470.80 km²; IBGE 2021). According to the Köppen-Geiger classification (Peel et al. 2007), the climate of the region was classified as Af (tropical group and humid forest subgroup), hot and humid, with heavy rainfall from Jan to Jul (Amazonian winter) and low rainfall from Aug to Dec, and an average temperature of 25 °C and average annual rainfall of 2,284 mm (Sá 1986; Neto & Lira 2022). The municipality of Oiapoque is partially composed of hydrographic basins of the Oiapoque, Cassiporé, and Uaçá Rivers, with 2 natural domains: floodplain and dense terra firme forest (Ferreira & Narciso 2018).

SAMPLING PROCEDURES

Fruits were collected from urban trees, residential backyards, and small orchards in the rural and urban areas of the municipality of Oiapoque (Amapá, Brazil). Sampling was performed randomly by collecting intact fruits that had recently fallen to the ground and were directly removed from the plants.

Fruits were collected from several plant species on Mar 15 and 16, Apr 25 to 29, Jul 4 to 7, Aug 29 to 31, and Sep 19 to 22 in 2022. Additionally, 1 fruit sample of *Ziziphus mauritiana* Lam. (Rhamnaceae) was collected on Jan 30, 2023.

Geographic coordinates of all collection points were recorded using the Datum SIRGAS 2000 (Geocentric Reference System for the Americas 2000) reference system. All samples, composed of several grouped fruits of the same plant species, were stored in plastic containers, wrapped in an organza bag, labeled, and transported to the Embrapa Amapá Plant Protection Laboratory in Macapá (Amapá, Brazil).

OBTAINING PUPAE AND ADULT INSECTS

We analyzed the fruits as described by Silva et al. (2011a). Fruits were counted, weighed, and arranged on plastic trays (30.3 × 22.1 × 7.5 cm) on a 2 cm layer of moistened vermiculite. Trays were covered with organza, which was secured using an elastic band.

Fruits were examined every 5 d, for 20 to 30 d for the presence of fruit fly pupae. After this period, the fruits (in general already almost completely consumed by fruit fly larvae) were placed in an oven at a temperature of 120 °C, to eliminate any immature forms, as recommended by Silva et al. (2011a) prior to disposal. The pupae obtained from the fruits of each sample were removed and transferred to transparent plastic bottles (8 cm in diameter) containing a thin layer of moistened vermiculite. Flasks were covered with organza and a vented lid before being placed in a room under controlled temperature (26 ± 0.5 °C), relative humidity (70 ± 10%), and photophase (12 h). Humidity in the trays and flasks was maintained by replacing the water with a pipette.

Flasks containing pupae were inspected daily for 30 d, a period sufficient for the emergence of all viable insects (Silva et al. 2011a). Fruit flies and emerging parasitoids were stored in glass vials containing 70% ethanol until taxonomic identification.

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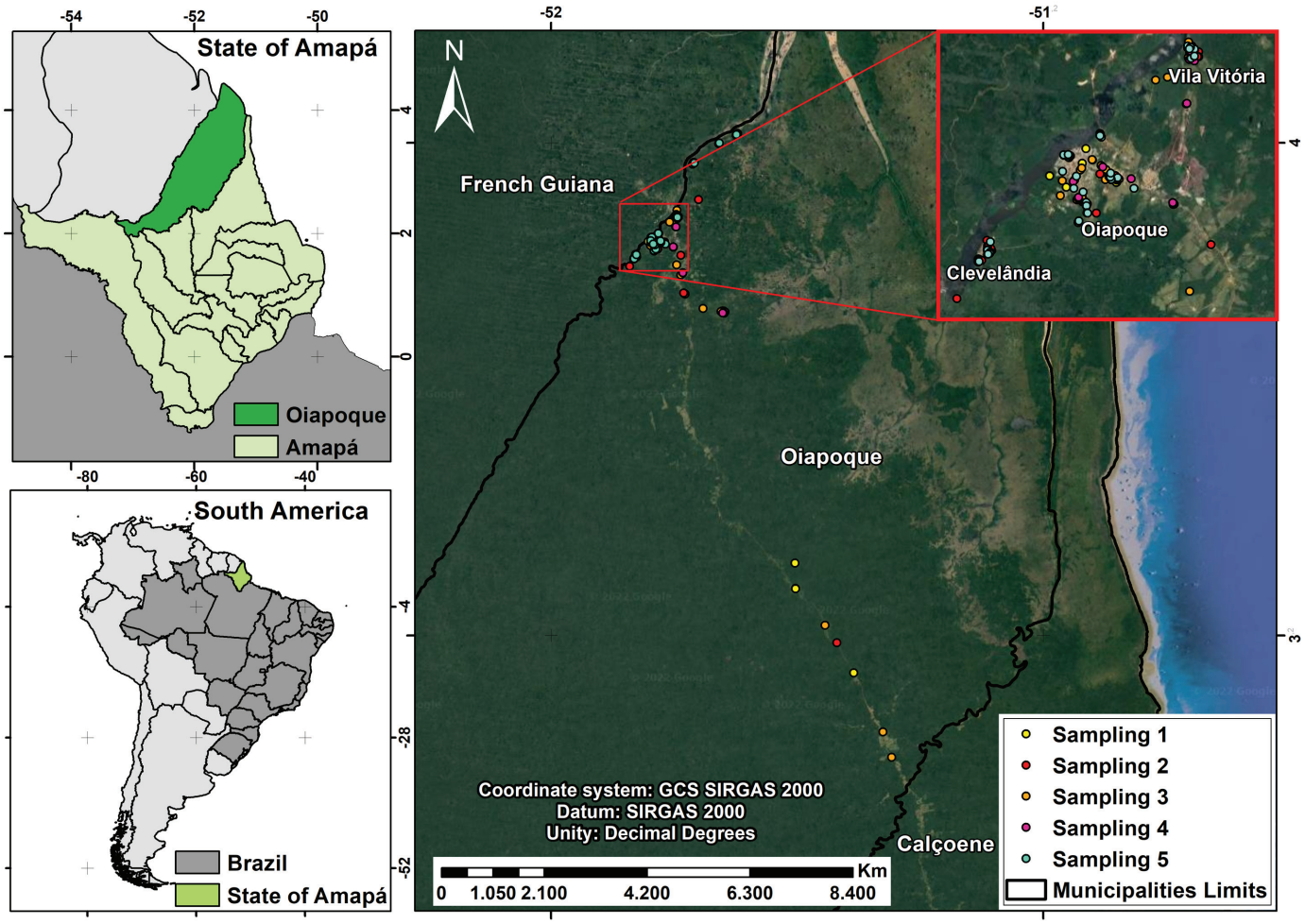

Fig. 1. Location of fruit sample collection points in the municipality of Oiapoque, state of Amapá, Brazil.

IDENTIFICATION OF COLLECTED INSECTS

Anastrepha specimens were identified using the dichotomous key described by Zucchi et al. (2011). Identification was based on observation of the terminalia of the females, apex of the extruded aculeus, using a stereomicroscope and an optical microscope (40×). Other characteristics, such as the patterns of wing bands, mesonotum, midterm, and subscutellum, also were examined. Specimens of *B. carambolae* were identified as described by Drew and Hancock (1994) and Schutze et al. (2014). Considering that since 1966, *B. carambolae* is a pest of quarantine importance in Brazil and given the similarity between *Bactrocera dorsalis* species complex (Wee & Tan, 2005), the Ministry of Agriculture and Livestock often performs molecular analyses on specimens collected from the states where it is present (see Supplementary Material). Braconidae parasitoids were identified as described by Canal and Zucchi (2000) and Marinho et al. (2011). The identification procedure for figitids followed Guimarães et al. (2003), Buffington and Ronquist (2006), and Ovruski et al. (2007). Figitidae specimens were deposited in the "Oscar Monte" Entomophagous Insect Collection at the Biological Institute (Biological Control Laboratory, Campinas, São Paulo, Brazil), under reference number IB-CBE-S-854 (curator: Valmir A. Costa). *Bactrocera carambolae*, *Anastrepha* spp., and Braconidae specimens were deposited at the Embrapa Amapá Plant Protection Laboratory.

IDENTIFICATION OF BOTANICAL MATERIAL

The collected fruits were used to evaluate the infestation by fruit fly larvae and to verify if the larvae were parasitized. To confirm the identification of plant species unknown by our team, we removed the branches containing their reproductive structures (flowers and fruits) and processed them into herbarium specimens using the mounting and preservation techniques described by Fidalgo and Bononi (1984). Plant species were identified by our research group using identification keys based on specialized literature (Rios & Pastore Jr. 2011; Lorenzi et al. 2015; Souza & Lorenzi 2019) and by comparing them with specimens available at the Herbário Amapaense (HAMAB), herbarium at the Amapá Institute for Scientific and Technological Research (Macapá, Amapá, Brazil), where some vouchers were deposited (listing number 020055, 020056, and 020057). We used World Flora Online (WFO 2023) to provide scientific names and author names of each plant species.

DATA ANALYSIS

We calculated the following parameters: (I) infestation index (number of puparia in the sample divided by sample mass in kilograms; expressed as number of puparia per kg of fruit), (II) percentage of emergence ([number of adults emerged divided by number of puparia in the

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sample] × 100), and (III) percentage of parasitism ([number of parasitoids emerged divided by number of puparia] × 100).

Results

In this study, we collected 240 samples (11,126 fruits; 288.8 kg) from 33 plant species (16 native and 17 introduced species) belonging to 19 families (Table 1). Fruit fly infestations were observed in 136 samples (56.7%) of 18 plant species among 12 families (Table 1). Of the total 12,196 puparia, we observed the emergence of 1,678 females and 1,824 males of 8 *Anastrepha* species, 2,257 females and 2,282 males of *B. carambolae*, and 5 species of parasitoids (3 Braconidae and 2 Figitidae species).

We reared 8 *Anastrepha* species from larvae to adults from several host plant species. *Anastrepha antunesi* Lima (11 females) was reared from *Spondias mombin* L. (Anacardiaceae); *A. coronilli* Carrejo and González (17 females) was reared from *Bellucia grossularioides* (L.) Triana (Melastomataceae); *A. distincta* Greene (80 females) was reared from *Inga edulis* Mart. (Fabaceae), *Inga laurina* (Sw.) Willd (Fabaceae), and *Psidium guajava* L. (Myrtaceae); *A. fraterculus* (Wiedemann) complex (68 females) was reared from *S. mombin*, *Spondias purpurea* L. (Anacardiaceae), and *P. guajava*; *A. obliqua* (Macquart) (257 females) was reared from *Averrhoa carambola* L. (Oxalidaceae), *S. purpurea*, *S. mombin*, and *P. guajava*; *A. turpiniae* Stone (1 female) was reared from *P. guajava*; *A. striata* Schiner (1,241 females and 1,386 males) was reared from *P. guajava* and *Psidium guineense* Sw. (Myrtaceae); and *A. sororcula* Zucchi (3 females) was reared from *S. mombin*.

Bactrocera carambolae was obtained from the fruits of 13 plant species: *Annona mucosa* Jacq. (Annonaceae), *Artocarpus heterophyllus* Lam. (Moraceae), *Averrhoa bilimbi* L. (Oxalidaceae), *A. carambola*, *Citrus* x *aurantium* L. (Rutaceae), *Citrus reticulata* Blanco (Rutaceae), *Malpighia emarginata* DC. (Malpighiaceae), *Passiflora quadrangularis* L. (Passifloraceae), *Pouteria caimito* Radlk. (Sapotaceae), *P. guajava*, *S. mombin*, *Syzygium malaccense* (L.) Merr. & L. M. Perry (Myrtaceae), and *Z. mauritiana* (Table 1).

We also obtained 3 species of Braconidae parasitoids: *Doryctobracon areolatus* (Szepligeti); 7 females and 3 males, *Opius bellus* Gahan; 14 females and 5 males, and *Utetes anastrephae* (Viereck); 8 females and 3 males and 2 species of Figitidae: *Aganaspis pelleranoi* (Brèthes); 13 females and 27 males and *Aganaspis nordlanderi* Wharton; 1 female and 1 male (Table 1). Specimens of the parasitoid *D. areolatus* were obtained from the tephritid-infested fruits of *B. grossularioides* and *P. guajava*. *Opius bellus* was obtained from *S. mombin*, and *U. anastrephae* was obtained from both *I. edulis* and *S. mombin*. The highest percentage of parasitism was observed in *B. grossularioides* (11.6%) (Table 1).

Discussion

This study is the most comprehensive survey conducted in the extreme north region of Brazil. Previously, there were only spot collections, except for the work carried out by Adaime et al. (2017), who collected 126 samples from 29 plant species of 18 families.

Bactrocera carambolae accounted for the majority (56.4%; 4,539) of all collected tephritids, followed by *Anastrepha* spp. (43.6%; 3,502). Highest abundance of tephritids was observed in *P. guajava*, with *A. striata* (1,236 females and 1,369 males) being the predominant species, followed by *B. carambolae* (416 females and 456 males). In contrast to the report of Adaime et al. (2017), *B. carambolae* was predominant over *Anastrepha* spp. in this study, possibly due to the collection of various fruits with high pest infestation, such as *P. guajava* (52.28 kg), *M. emarginata* (19.43 kg), *A. carambola* (21.71 kg), and *S. malaccense* (9.85 kg).

Notably, *B. carambolae* was obtained from 13 host plant species. We observed that the larvae were feeding exclusively on the fruit pulp. The species had never been obtained from so many host plants in surveys in Amapá. Prior to this work, *B. carambolae* had the following hosts in Oiapoque: *A. carambola*, *C. aurantium*, *M. emarginata*, *P. guajava* and *S. malaccense* (Creão 2003; Adaime et al. 2016a; Deus et al. 2016a; Adaime et al. 2017; Sousa et al. 2019). *Bactrocera carambolae* also infests *Anacardium occidentale* L. (Anacardiaceae), *A. bilimbi*, *Byrsonima crassifolia* (L.) Kunth (Malpighiaceae), *Calycolpus goetheanus* (Mart. Ex DC.) (Myrtaceae), *Capsicum chinense* Jacq. (Solonaceae), *C. reticulata*, *Chrysobalanus icaco* L. (Chrysobalanaceae), *Eugenia stipitata* McVaugh (Myrtaceae), *Eugenia uniflora* L. (Myrtaceae), *Licania* sp. (Chrysobalanaceae), *Mangifera indica* L. (Anacardiaceae), *Manilkara zapota* (L.) P. Royen (Sapotaceae), *P. caimito*, *Pouteria macrophylla* (Lam.) Eyma (Sapotaceae), *P. guineense*, *S. mombin*, *S. purpurea, Syzygium cumini* (L.) Skeels (Myrtaceae), *Syzygium jambos* (L.) Alston (Myrtaceae), and *Syzygium samarangense* (Blume) Merr. & L.M. Perry (Myrtaceae) in other municipalities of Amapá (Adaime et al. 2016a; Belo et al. 2020).

To the best of our knowledge, our study adds 3 new records to the list of host plants for *B. carambolae* in Brazil (*A. heterophyllus*, *P. quadrangularis* and *Z. mauritiana*), 2 of them (*A. heterophyllus* and *P. quadrangularis*) new records for South America (Fig. 2). Also, the occurrence of *B. carambolae* in *P. quadrangularis* is probably the first record worldwide.

The sample of *A. heterophyllus* infested by *B. carambolae* was collected in the backyard of a residence in an urban area of Vila Vitória, close to the border with French Guiana. Less than 100 m from this plant, there were fruits of *A. carambola* and *P. guajava* infested by the pest. *Artocarpus heterophyllus*, known as jackfruit in Brazil, belongs to the Moraceae family and is native to Southeast Asia (Prakash et al. 2009). In Brazil, *A. heterophyllus* is an invasive species with a high density of individuals, high regeneration efficiency, and allelopathy (Boni et al. 2009; Abreu & Rodrigues 2010). It is economically important, and its fruits, wood, leaves, and latex are used for various purposes (Corrêa 1984). In Northeast Brazil, jackfruit is popular for its sweet taste and widely used in sweets, jellies, juices, and compotes (Jagtap et al. 2010). *Artocarpus heterophyllus* is also a host of *B. carambolae* at the center of origin (Southeast Asia) of the pest (Allwood et al. 1999; Chinajariyawong et al. 2000). In South America, specifically in Suriname (van Sauers-Muller 2005) and French Guiana (Vayssières et al. 2013), no fruit infestation by *B. carambolae* has been reported in this species. In Brazil, only *A. striata* infestations have been reported in fruits of *A. heterophyllus* (Silva et al. 2009).

Fruits of infested *P. quadrangularis* were obtained in the urban area of the municipality, in the backyard of a residence. Less than 50 m away there were fruits of *P. guajava* infested by the pest. *Passiflora quadrangularis*, native to the Neotropics, is known as passion fruit melon or giant passion fruit in Brazil because of its size and shape. It is widely distributed in the tropical regions of the world and produced on a small scale, as it is usually cultivated close to its place of consumption due to the challenges of post-harvest conservation. It is cultivated throughout tropical America; however, some authors consider it to be native to the Amazon region and South America (Montero et al. 2013). In Southeast Asia, there is only 1 report of the infestation of *P. quadrangularis* by *Bactrocera papayae*

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Table 1. Infestation by fruit flies in different plant species in the municipality of Oiapoque, Amapá, Brazil (Mar to Sep 2022).

Families *Scientific names** Vernacular names in Brazil	**Origin** **N/I**	**CS/IS** **(n)**	**Fruits** **(n)**	**Mass** **(kg)**	**P** **(n)**	**I** **(PP/kg)**	**E** **(%)**	**Fruit flies**** *A. = Anastrepha* *B. = Bactrocera*	**PP** **(%)**	**Parasitoids** *A. = Aganaspis* *D. = Doryctobracon* *O. = Opius* *U. = Utetes*
Anacardiaceae										
Anacardium occidentale L. Caju	N	14/0	175	13.12						
Mangifera indica L. Manga	I	1/0	1	0.22						
Spondias mombin L. Taperebá	N	8/8	740	9.18	902	98.3	74.8	*A. antunesi* (11) *A. fraterculus* (46) *A. obliqua* (244) *A. sororcula* (3) *Anastrepha* ♂ (343) *B. carambolae* (1♀)	3.0	*O. bellus* (14♀+5♂) *U. anastrephae* (5♀+3♂)
Spondias purpurea L. Siriguela	I	2/2	89	0.53	13	24.5	38.5	*A. fraterculus* (4) *A. obliqua* (1)		
Annonaceae										
Annona mucosa Jacq. Biribá	N	3/1	17	5.27	1	0.2	100	*B. carambolae* (1♂)		
Arecaceae										
Adonidia merrillii (Becc.) Becc. Palmeira-de-manila	I	1/0	387	2.02						
Caricaceae										
Carica papaya L. Mamão	I	5/0	12	5.69						
Chrysobalanaceae										
Chrysobalanus icaco L. Ajuru	N	1/0	12	0.18						
Clusiaceae										
Clusia grandiflora Splitg. Cebola-da-mata	N	1/0	10	0.54						
Fabaceae										
Alexa grandiflora Ducke Melancieira	N	1/0	5	0.55						
Inga edulis Mart. Ingá	N	8/6	60	13.89	388	27.9	9.3	*A. distincta* (17) *Anastrepha* ♂ (16)	0.8	*U. anastrephae* (3♀)
Inga laurina (Sw.) Willd. Ingá-branco	N	3/3	537	4.59	297	64.7	30.3	*A. distincta* (62) *Anastrepha* ♂ (26)		*A. nordlanderi* (1♀+1♂)
Malpighiaceae										
Bunchosia glandulifera (Jacq.) Kunth Marmeleiro, café-falso	I	3/0	252	2.01						
Malpighia emarginata DC. Acerola	I	36/20	5,092	19.43	1,765	90.8	45.0	*Anastrepha* ♂ (1) *B. carambolae* (410♀+383♂)		

*According to World Flora Online – WFO (2023). ***Anastrepha* males were only quantified, not identified at the species level, except for *A. striata*.
N: native; I: introduced; CS: collected samples; IS: infested samples; P: puparia; I: infestation; E: emergence; ♀: female; ♂: male; PP: percentage of parasitism

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Table 1. (Continued) Infestation by fruit flies in different plant species in the municipality of Oiapoque, Amapá, Brazil (Mar to Sep 2022).

Families *Scientific names** Vernacular names in Brazil	**Origin** **N/I**	**CS/IS** **(n)**	**Fruits** **(n)**	**Mass** **(kg)**	**P** **(n)**	**I** **(PP/kg)**	**E** **(%)**	**Fruit flies**** *A. = Anastrepha* *B. = Bactrocera*	**PP** **(%)**	**Parasitoids** *A. = Aganaspis* *D. = Doryctobracon* *O. = Opius* *U. = Utetes*
Melastomataceae										
Bellucia grossularioides (L.) Triana Goiaba-de-anta	N	4/3	208	1.66	43	18.1	81.4	*A. coronilli* (17) *Anastrepha* ♂ (13)	11.6	*D. areolatus* (4♀+1♂) *A. pelleranoi* (1♂)
Moraceae										
Artocarpus altilis (Parkinson) Fosberg Fruta-pão	I	3/0	19	15.58						
Artocarpus heterophyllus Lam. Jaca	I	9/1	14	51.35	5	0.1	40.0	*B. carambolae* (2♀)		
Myrtaceae										
Calycolpus goetheanus (Mart. ex DC.) O.Berg	N	1/0	10	0.08						
Psidium guajava L. Goiaba	N	61/57	1,137	52.28	4,987	95.4	71.5	*A. distincta* (1) *A. fraterculus* (18) *A. obliqua* (1) *A. striata* (1,236♀+1,369♂) *A. turpiniae* (1) *Anastrepha* ♂ (24) *B. carambolae* (416♀+456♂)	0.8	*D. areolatus* (3♀+2♂) *A. pelleranoi* (13♀+26♂)
Psidium guineense Sw. Araçá-do-campo	N	1/1	36	0.59	25	42.5	92.0	*A. striata* (5♀+17♂) *Anastrepha*♂ (1)		
Syzygium malaccense (L.) Merr. & L.M.Perry Jambo-vermelho	I	8/7	227	9.85	404	41.0	80.2	*B. carambolae* (153♀+171♂)		
Oxalidaceae										
Averrhoa bilimbi L. Limão-de-caiena	I	14/3	1,008	14.15	5	0.4	80.0	*B. carambolae* (4♂)		
Averrhoa carambola L. Carambola	I	20/18	285	21.71	2,107	97.1	73.7	*A. obliqua* (11) *Anastrepha* ♂ (13) *B. carambolae* (745♀+784♂)		
Passifloraceae										
Passiflora quadrangularis L. Maracujá-açu	N	4/2	14	21.72	75	3.5	22.7	*B. carambolae* (10♀+7♂)		
Rhamnaceae										
Ziziphus mauritiana Lam. Dão	I	1/1	196	1.62	1,146	707.4	86.2	*B. carambolae* (517♀+471♂)		
Rubiaceae										
Genipa americana L. Jenipapo	N	3/0	9	2.10						
Rutaceae										
Citrus aurantifolia (Christm.) Swingle Limão-galego	I	5/0	13	3.65						
Citrus japonica Thunb. Kumquat	I	2/0	63	0.99						

*According to World Flora Online – WFO (2023). ***Anastrepha* males were only quantified, not identified at the species level, except for *A. striata*.
N: native; I: introduced; CS: collected samples; IS: infested samples; P: puparia; I: infestation; E: emergence; ♀: female; ♂: male; PP: percentage of parasitism

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Table 1. (Continued) Infestation by fruit flies in different plant species in the municipality of Oiapoque, Amapá, Brazil (Mar to Sep 2022).

Families *Scientific names** Vernacular names in Brazil	**Origin** **N/I**	**CS/IS** **(n)**	**Fruits** **(n)**	**Mass** **(kg)**	**P** **(n)**	**I** **(PP/kg)**	**E** **(%)**	**Fruit flies**** *A. = Anastrepha* *B. = Bactrocera*	**PP** **(%)**	**Parasitoids** *A. = Aganaspis* *D. = Doryctobracon* *O. = Opius* *U. = Utetes*
Citrus reticulata Blanco Tangerina	I	4/1	106	6.99	20	2.9	15.0	*Anastrepha* ♂ (1) *B. carambolae* (1♀+1♂)		
Citrus x *aurantium* L. Laranja-da-terra	I	10/1	30	5.73	4	0.7	100.0	*B. carambolae* (2♀+2♂)		
Sapindaceae										
Nephelium lappaceum L. Rambotão	I	1/10	15	0.44						
Sapotaceae										
Pouteria caimito Radlk. Abiu	N	1/1	42	0.58	9	15.4	22.2	*B. carambolae* (2♂)		
Siparunaceae										
Siparuna guianensis Aubl. Capitiú	N	1/0	305	0.51						
TOTAL		**240/136**	**11,126**	**288.8**	**12,196**					

*According to World Flora Online – WFO (2023). ***Anastrepha* males were only quantified, not identified at the species level, except for *A. striata*.
N: native; I: introduced; CS: collected samples; IS: infested samples; P: puparia; I: infestation; E: emergence; ♀: female; ♂: male; PP: percentage of parasitism

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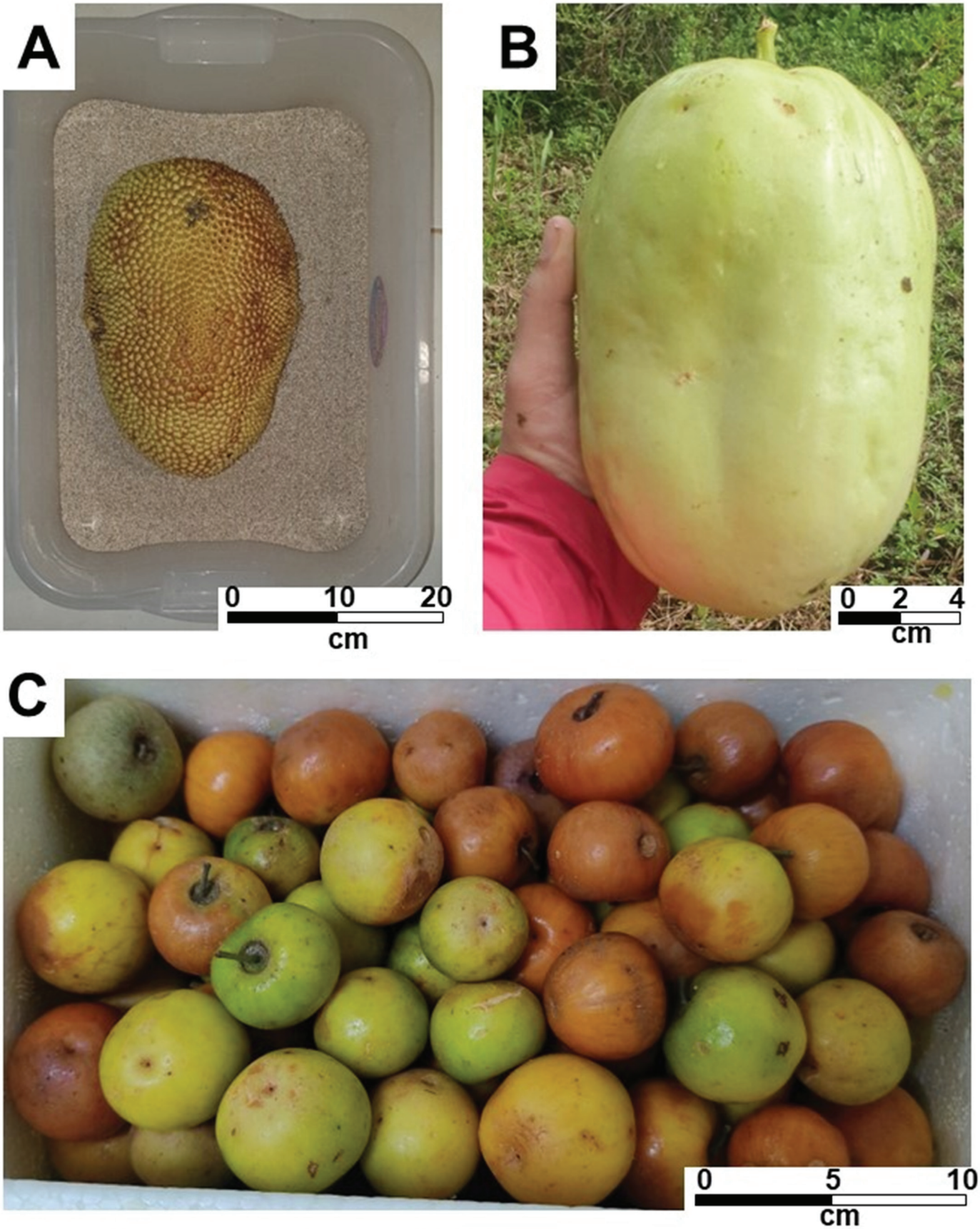

Fig. 2. New hosts of *Bactrocera carambolae*: A) *Artocarpus heterophyllus* (Moraceae); B) *Passiflora quadrangularis* (Passifloraceae); C) *Ziziphus mauritiana* (Rhamnaceae). Photos: José Victor T. A. Costa.

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Drew & Hancock (Allwood et al. 1999). In South America, no infestation of *P. quadrangularis* by *B. carambolae* has been reported in French Guiana nor Suriname (van Sauers-Muller 1991, 2005; Vayssières et al. 2013).

In the case of *Z. mauritiana*, fruits were collected in the urban area of the municipality, in the locality called Patauá, in a backyard of a residence. Nearby, there were plants of *P. guajava*, but the fruits were not infested by the pest. *Ziziphus mauritiana* is native to the tropical and subtropical areas of India and Southeast Asia (Lorenzi et al. 2015). In Brazil, it is known as "dão" and used for urban afforestation in gardens in the state of Roraima (Ronchi-Teles et al. 2008). Moreover, its fruits, when light green, yellow, or red, are widely consumed in Brazil (Lorenzi et al. 2015). Until this study, the only species of fruit fly obtained from *Z. mauritiana* in Brazil was *Anastrepha zenildae* Zucchi, in Boa Vista, Roraima (Ronchi-Teles et al. 2008; Marsaro Júnior et al. 2011; Dutra et al. 2013).

Among the species of *Anastrepha*¸ *A. striata* was the predominant species in Oiapoque because of its association with *P. guajava*, the most abundantly sampled plant species in this study (Table 1). A strong association between *A. striata* and *P. guajava* is commonly reported in the Brazilian Amazon (Adaime et al. 2023).

Highest infestation by fruit flies were observed in *S. mombin* (98.3 puparia/kg), *A. carambola* (97.1 puparia/kg), *P. guajava* (95.4 puparia/kg), and *M. emarginata* (90.8 puparia/kg). *Anastrepha obliqua* was the main species found in *S. mombin*, consistent with the findings of Deus et al. (2016b). In *P. guajava*, the highest infestation was of *A. striata*, followed by *B. carambolae*, similar to the results of Sousa et al. (2019). *Bactrocera carambolae* infests common guava fruits as do *Anastrepha* species; however, its presence does not affect the autochthonous populations. Deus et al. (2016a) reported that the spatial distribution of *A. striata* and *B. carambolae* may enable their co-occurrence in fruits and that the high degree of aggregation of these species in the fruits indicates the coexistence potential of these tephritids in guava in northern Brazil.

Coexistence of *B. carambolae* with other species of the genus *Anastrepha* was less evident in *A. carambola* and *M. emarginata*, which were predominantly infested by *B. carambolae*. A high infestation was observed in *A. carambola* as the fruit is the preferred host of the pests, having co-evolved in the native habitat of the pest. *Psidium guajava* and *A. carambola* are the primary hosts of *B. carambolae* in Southeast Asia and Suriname (Allwood et al. 1999; van Sauers-Muller 2005). Although *M. emarginata* is originally from tropical America, *B. carambolae* has adapted well to infest this plant. Van Sauers-Muller (2005) reported *M. emarginata* as an important host plant in Suriname. In French Guiana, Vayssières et al. (2013) reported greater infestation in *M. emarginata* than in *P. guajava* and demonstrated *A. carambola* and *M. emarginata* as the species widely infested by the carambola fruit fly.

In the state of Amapá, Lemos et al. (2014) reported high infestation in *M. emarginata*, reaching 620.7 puparia/kg. We suspect that *M. emarginata* has a significant impact on the persistence of *B. carambolae* in the municipality of Oiapoque as we could observe females laying eggs on green fruits even during the fruit collection process in this study (personal observation).

Vayssières et al. (2013) reported that *B. carambolae* became dominant over time on 4 hosts (*A. carambola*, *M. emarginata*, *Spondias dulcis* G. Forst. (Anacardiaceae), and *S. samarangense*) that were previously predominantly infested by species of the genus *Anastrepha* in French Guiana, which may be related to competitive shifts in species. Between 1994 and 2003, no native fruit trees were reported to be infested with the carambola fruit fly in French Guiana (Vayssières et al. 2003). However, since 2005, some specimens of *B. carambolae* have been obtained from the native fruit plants of this region (Vayssières et al. 2013).

Despite the existence of an official control program in Brazil, *B. carambolae* has been dominant in Oiapoque since 1996, possibly due to the adaptation of the species to new hosts. All studies on host plants of this pest were carried out in the state of Amapá, where *B. carambolae* has several host plant species, including *P. guajava*, *A. carambola*, *S. malaccense*, and *M. emarginata*, which are the most frequently infested species, unlike 2 decades ago, when this pest almost exclusively infested *A. carambola* (R. Adaime, personal communication). *Bactrocera carambolae* is capable of infesting fruits of plant species native to the Amazon region, such as *E. stipitata* and *P. macrophylla*, using them as alternative hosts. However, so far this has only been recorded in areas already altered by human activity (Lemos et al. 2014). Belo et al. (2020) reported the species *C. goetheanus* as a host plant for *B. carambolae*, native to the Neotropical region and naturally occurring in peri-urban forests, revealing the adaptive capacity of this species. Iwahashi (1999, 2000) observed that *B. carambolae* evolved an aculeus-length adaptation capable of ovipositing on host plants native to Asian tropical forests. Therefore, complementary studies on the length of the aculeus must be conducted to confirm whether this adaptation also is observed in *B. carambolae* in the tropical forests of the Amazon region and in urban and peri-urban areas.

Considering the results obtained in this work and others already carried out, it is known that in addition to *B. carambolae*, 23 species of *Anastrepha* were reported in Oiapoque, and the host plants are unknown for 13 of them because they were captured in McPhail-type traps (Ronchi-Teles 2000; Carvalho 2003; Norrbom & Uchôa 2011; Trindade & Uchôa 2011). In this study, there were no new records of species of the genus *Anastrepha* in this municipality. However, we identified 8 new associations between species of *Anastrepha* and host plants. Additionally, 8 new associations of *B. carambolae* with host species were identified (Table 2).

Braconidae species identified in this study had previously been reported in the Brazilian Amazon (Sousa et al. 2021, 2023). Between the 2 species of Figitidae identified in this study, *A. pelleranoi*, which has previously been reported in the Brazilian Amazon (states of Amapá, Amazonas, Pará and Roraima) and other Brazilian states (Sousa et al. 2021; Zucchi & Moraes 2023), was the most abundant. The other Figitidae species, *A. nordlanderi*, previously was reported only in the states of Amazonas and Santa Catarina in Brazil (Zucchi & Moraes 2023). However, our study presents the first record of *A. nordlanderi* in the state of Amapá. Considering all the studies carried out in Oiapoque, 7 species of parasitoids are currently reported (Table 3).

Notably, except *A. turpiniae*, all Tephritidae species identified in this study have previously been reported in French Guiana border via the municipality of Oiapoque (Brazil) (Vayssières et al. 2013). Interestingly, we did not detect the quarantine pest, *A. suspensa*, in the study area. Adaime et al. (2018a) reported a significant risk of introducing this species in Brazil. Therefore, it is important to conduct further studies, focusing on fruit sampling, in this region to validate these findings.

Due to the great socioeconomic importance of *B. carambolae* for national fruit growing (Silva et al. 2004; Godoy et al. 2011; Lemos et al. 2014; Ferreira and Rangel 2015; Miranda and Adami 2015), it is imperative that studies be carried out to identify new host plants. This knowledge then can be used in official pest control programs, with the adoption of more targeted and effective control measures. Moreover, future studies should focus on plant species native to South America to verify the possible adaptation of pests to fruits in this region.

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Table 2. List of fruit flies (Tephritidae) and their host plants in the municipality of Oiapoque, Amapá, Brazil.

Species	Sampling methods	Host plants	References
Anastrepha amita Zucchi	McPhail trap	NA	1
Anastrepha antunesi Lima	Fruit	*Spondias mombin* L.	2, TP
Anastrepha binodosa Stone	McPhail trap	NA	1
Anastrepha coronilli Carrejo & González	McPhail trap	NA	1, 3
	Fruit	*Bellucia grossularioides* (L.) Triana	4, 5, TP
Anastrepha dissimilis Stone	McPhail trap	NA	1
Anastrepha distincta Greene	McPhail trap	NA	1
	Fruit	*Inga edulis* Mart.	4, TP
	Fruit	*Inga laurina* (Sw.) Willd#	TP
	Fruit	*Psidium guajava* L.#	TP
Anastrepha duckei Lima	McPhail trap	NA	1
Anastrepha flavipennis Greene	McPhail trap	NA	1
Anastrepha fraterculus (Wiedemann)	McPhail trap	NA	1
	Fruit	*Psidium guajava* L.	4, 6, 7, TP
	Fruit	*Spondias mombin* L.#	TP
	Fruit	*Spondias purpurea* L.#	TP
Anastrepha furcata Lima	McPhail trap	NA	1
Anastrepha leptozona Hendel	Fruit	*Pouteria caimito* Radlk.	4
Anastrepha minensis Lima	McPhail trap	NA	1
Anastrepha mixta Zucchi	McPhail trap	NA	1
Anastrepha obliqua (Macquart)	McPhail trap	NA	1
	Fruit	*Averrhoa carambola* L.	4, TP
	Fruit	*Psidium guajava* L.#	TP
	Fruit	*Spondias mombin* L.	2, 4, TP
	Fruit	*Spondias purpurea* L.#	TP
Anastrepha oiapoquensis Norrbom & Uchôa	McPhail trap	NA	1, 8
Anastrepha pseudoparallela (Loew)	McPhail trap	NA	1
Anastrepha rafaeli Norrbom & Korytkowski	McPhail trap	NA	1
Anastrepha siculigera Norrbom & Uchôa	McPhail trap	NA	1, 8
Anastrepha sororcula Zucchi	McPhail trap	NA	1
	Fruit	*Spondias mombin* L.#	TP
Anastrepha striata Schiner	McPhail trap	NA	3, 9
	Fruit	*Psidium guajava* L.	4, 6, 7, 10, TP
	Fruit	*Psidium guineense* Sw.#	TP
	Fruit	*Syzygium malaccense* (L.) Merr. & L.M. Perry	4
Anastrepha submunda Lima	McPhail trap	NA	1
Anastrepha turpiniae Stone	Fruit	*Spondias mombin* L.	11
	Fruit	*Psidium guajava* L.	11, TP
Anastrepha zacharyi Norrbom	Fruit	*Bellucia egensis* (DC.) Penneys, Michelangeli, Judd and Almeda	13

#New associations of fruit flies and hosts for the municipality of Oiapoque;
▲First record in South America;
[1]Trindade & Uchôa (2011); [2]Sousa et al. (2016); [3]Ronchi-Teles (2000); [4]Adaime et al. (2017); [5]Adaime et al. (2018b); [6]Deus et al. (2016a); [7]Sousa et al. (2019); [8]Norrbom & Uchôa (2011); [9]Carvalho (2003); [10]Ronchi-Teles et al. (1996); [11]Creão (2003); [12]Adaime et al. (2016a); [13]Adaime et al. (2016b); NA: not available; TP: this paper.

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Table 2. (Continued) List of fruit flies (Tephritidae) and their host plants in the municipality of Oiapoque, Amapá, Brazil.

Species	Sampling methods	Host plants	References
Bactrocera carambolae Drew & Hancock	McPhail trap	NA	1, 3, 9
	Fruit	*Annona mucosa* Jacq.[#]	TP
	Fruit	*Artocarpus heterophyllus* Lam[▲]	TP
	Fruit	*Averrhoa bilimbi* L.[#]	TP
	Fruit	*Averrhoa carambola* L.	4, 11, TP
	Fruit	*Citrus* x *aurantium* L.	12, TP
	Fruit	*Citrus reticulata* Blanco[#]	TP
	Fruit	*Malpighia emarginata* Sessé & Moc. ex. DC.	4, TP
	Fruit	*Passiflora quadrangularis* L.[▲]	TP
	Fruit	*Pouteria caimito* Radlk.[#]	TP
	Fruit	*Psidium guajava* L.	4, 6, 7, TP
	Fruit	*Spondias mombin* L.[#]	TP
	Fruit	*Syzygium malaccense* (L.) Merr. & L.M. Perry	4, TP
	Fruit	*Ziziphus mauritiana* Lam.#	TP

[#]New associations of fruit flies and hosts for the municipality of Oiapoque;
[▲]First record in South America;
[1]Trindade & Uchôa (2011); [2]Sousa et al. (2016); [3]Ronchi-Teles (2000); [4]Adaime et al. (2017); [5]Adaime et al. (2018b); [6]Deus et al. (2016a); [7]Sousa et al. (2019); [8]Norrbom & Uchôa (2011); [9]Carvalho (2003); [10]Ronchi-Teles et al. (1996); [11]Creão (2003); [12]Adaime et al. (2016a); [13]Adaime et al. (2016b); NA: not available; TP: this paper.

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Table 3. List of parasitoids and their hosts in the municipality of Oiapoque, Amapá, Brazil.

Species	Host plants	References
Aganaspis pelleranoi (Brèthes)	*Psidium guajava* L.	1, TP
	Bellucia grossularioides (L.) Triana	TP
	Spondias mombin L.	1
Aganaspis nordlanderi Wharton	*Inga laurina* (Sw.) Willd	TP
Asobara anastrephae (Muesebeck)	*Psidium guajava* L.	1
	Spondias mombin L.	1, 2
Doryctobracon adaimei Marinho & Penteado-Dias	*Psidium guajava* L.	3
Doryctobracon areolatus (Szépligeti)	Host not identified	4
	Bellucia egensis (DC.) Penneys, Michelangeli, Judd, and Almeda	5
	Bellucia grossularioides (L.) Triana	6, 7, TP
	Pouteria caimito Radlk.	1
	Psidium guajava L.	1, 3, 6, 8, TP
	Spondias mombin L.	1, 8
	Syzygium malaccense (L.) Merr. & L.M. Perry	6
Opius bellus Gahan	*Spondias mombin* L.	2, 8, TP
	Psidium guajava L.	1
	Spondias mombin L.	1
Utetes anastrephae (Viereck)	*Psidium guajava* L.	1
	Inga edulis Mart.	TP
	Spondias mombin L.	1, 2, 8, TP

[1]Carvalho (2003); [2]Sousa *et al*. (2016); [3]Sousa *et al*. (2019); [4]Ronchi-Teles (2000); [5]Adaime *et al*. (2016b); [6]Adaime *et al*. (2017); [7]Adaime *et al*. (2018b), [8]Creão (2003); TP: this paper.

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