New Findings on Carambola Fruit Fly Hosts in South America

Authors: Torres Alves Costa, José Victor, Socorro Miranda de Sousa, Maria do, de Jesus, Cristiane Ramos, de Souza-Filho, Miguel Francisco, Costa, Valmir Antonio, et al.

Source: Florida Entomologist, 106(3) : 161-174

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.106.0303

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-

[1]Universidade Federal do Amapá, Programa de Pós-graduação em Biodiversidade e Biotecnologia, Macapá, Amapá, Brazil; E-mail: jose.torres@agro.gov.br (J.V.T.A.C.)
[2]Universidade Federal do Amapá, Programa de Pós-graduação em Biodiversidade Tropical, Macapá, Amapá, Brazil; E-mail: socorro-ap@hotmail.com (M.S.M.S.)
[3]Embrapa Amapá, Proteção de Plantas, Macapá, Amapá, Brazil; E-mail: cristiane.jesus@embrapa.br (C.R.J.), ricardo.adaime@embrapa.br (R.A.)
[4]Instituto Biológico, Centro Avançado de Pesquisa e Desenvolvimento em Sanidade Agropecuária, Campinas, São Paulo, Brazil; E-mail: miguel.souza@sp.gov.br (M.F.S-F.), valmir.costa@sp.gov.br (V.A.C.)
[5]Universidade do Estado do Amapá, Macapá, Amapá, Brazil; E-mail: breno.silva@ueap.edu.br (B.M.S.S.), jessicamonteiro.ap@gmail.com (J.P.M.O.)
*Corresponding author; E-mail: ricardo.adaime@embrapa.br (R.A.)

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.

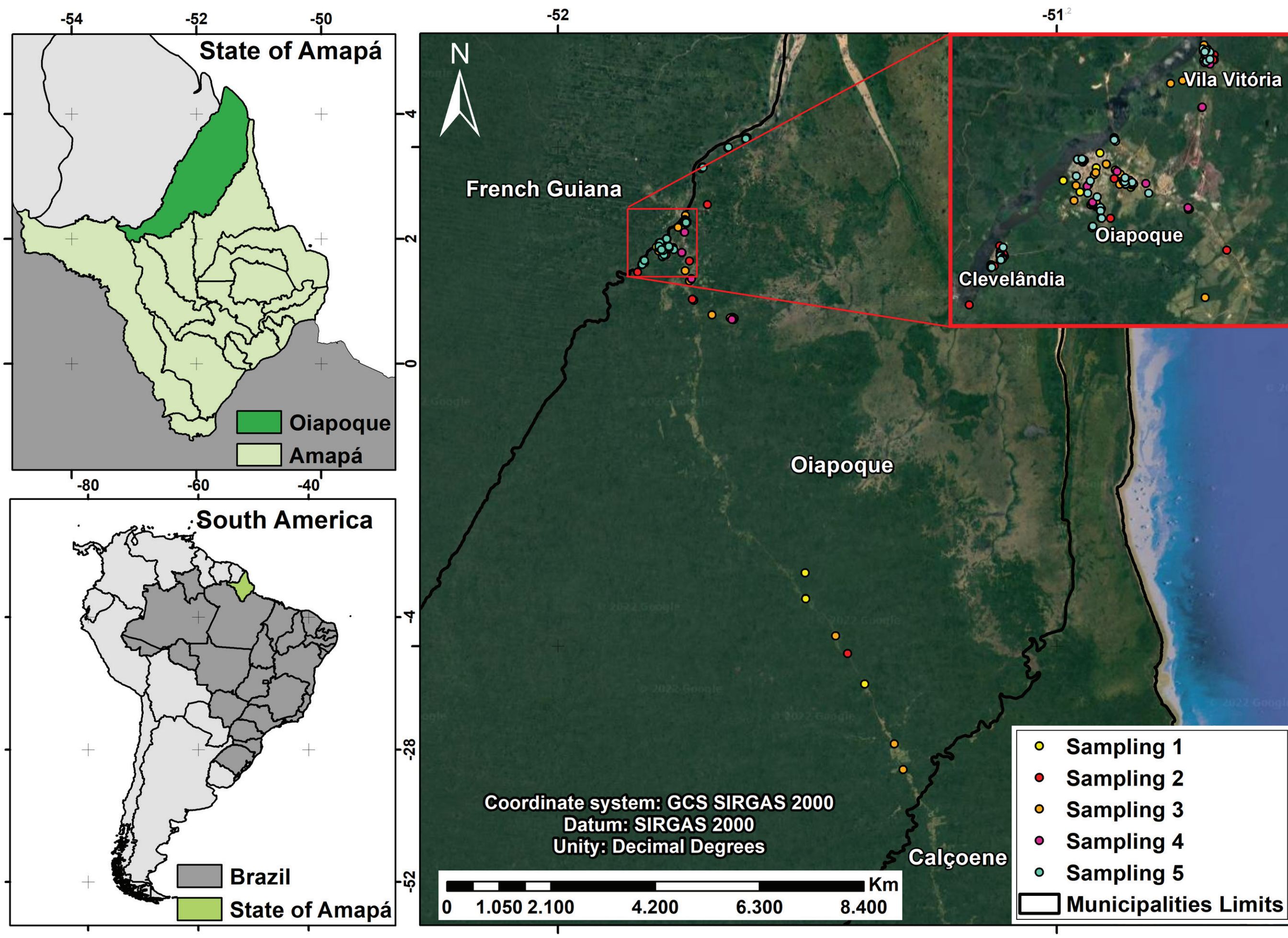

Fig. 1. Location of fruit sample collection points in the municipality of Oiapoque, state of Amapá, Brazil.

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 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*

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

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

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

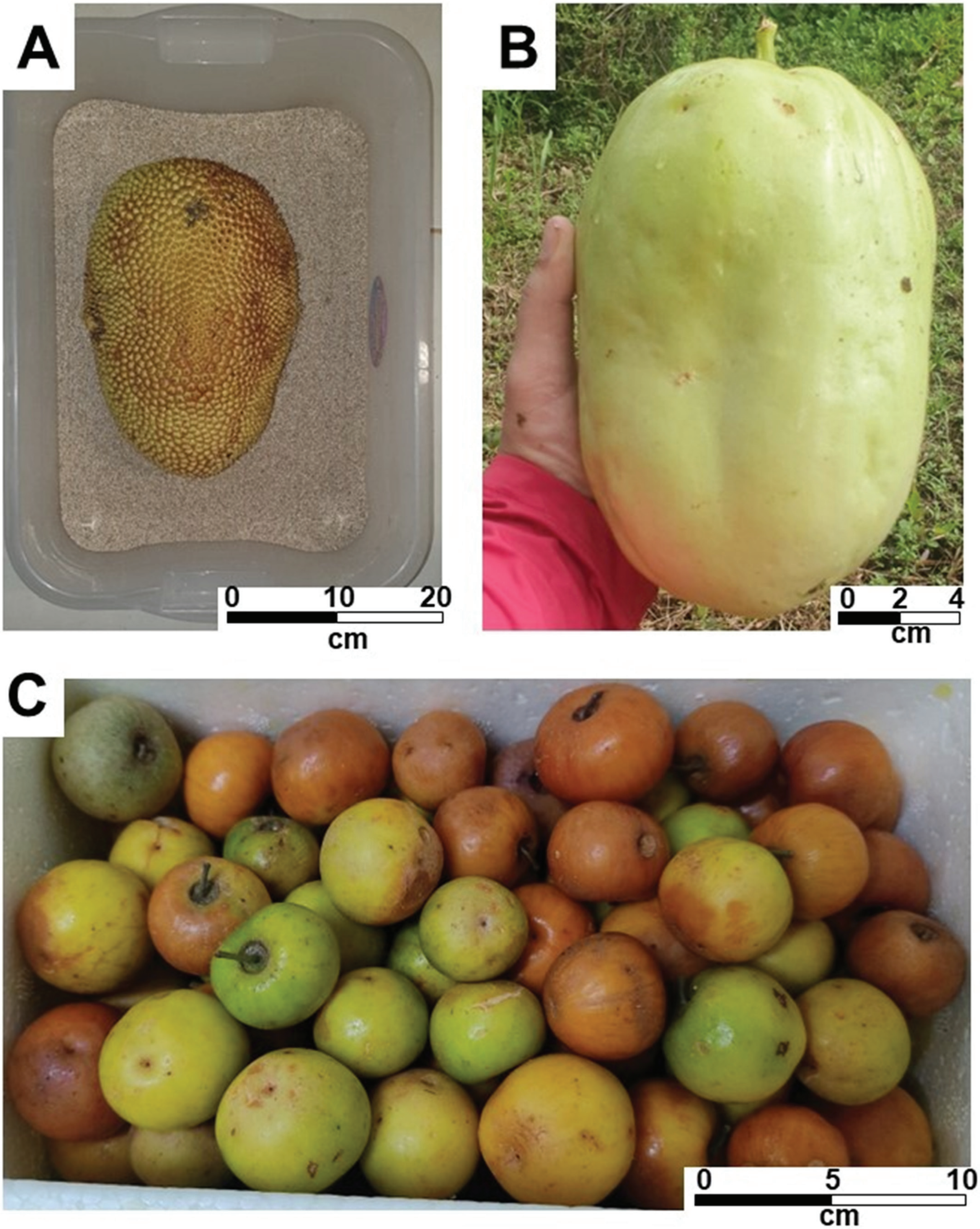

Fig. 2. New hosts of *Bactrocera carambolae*: A) *Artocarpus heterophyllus* (Moraceae); B) *Passiflora quadrangularis* (Passifloraceae); C) *Ziziphus mauritiana* (Rhamnaceae). Photos: José Victor T. A. Costa.

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.

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.

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.

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.

Acknowledgments

We would like to thank Josenilson Alves de Sousa Amaral, Cleofaz de Paula Abreu, Juarez Muniz Chagas de Castro, Marco Antônio do Vale Pereira, Denilson Camilo, and Alfredo da Conceição Magalhães for their assistance in sample collection. We are also grateful to Adriana Bariani, Jacivaldo Barbosa, and Alain Khristian Borges Teixeira Matos for their support with laboratory activities. VAC would like to thank the Instituto Nacional de Ciência e Tecnologia dos Hymenoptera Parasitoides (INCT-Hympar; CNPq Process 465562/2014-0) for financial support. The authors thank the Department of Plant Health and Agricultural Inputs of the Ministry of Agriculture and Livestock, for the authorization granted to carry out this research (Process 21008.000524/2022-14). We would like to thank Editage (www.editage.com) for English language editing.

References Cited

Abreu RCR, Rodrigues PJFP. 2010. Exotic tree *Artocarpus heterophyllus* (Moraceae) invades the Brazilian Atlantic Rainforest. Rodriguésia 61: 677–688.

Adaime R, Jesus CR, Lima AL, Fidelis EG. 2018a. *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), pp. 123–136 *In* Fidelis EG, Lohmann TR, Silva ML, Parizzi P, Barbosa FFL [eds.], Priorização de Pragas Quarentenárias Ausentes no Brasil. Embrapa, Brasília, Brazil.

Adaime R, Jesus-Barros CR, Bariani A, Lima AL, Cruz KR, Carvalho JP. 2016a. Novos registros de hospedeiros da mosca-da-carambola (*Bactrocera carambolae*) no estado do Amapá, Brasil. Embrapa Amapá (Comunicado Técnico 146), Macapá, Brazil.

Adaime R, Jesus-Barros CR, Uramoto K, Norrbom AL, Zucchi RA. 2016b. First record of *Anastrepha zacharyi* Norrbom (Diptera, Tephritidae) in Brazil, and notes on its host plant and parasitoid. Proceedings of the Entomological Society of Washington 118: 636–640.

Adaime R, Sousa MSM, Jesus-Barros CR, Deus EG, Pereira JF, Strikis PC, Souza-Filho MF. 2017. Frugivorous flies (Diptera: Tephritidae, Lonchaeidae), their host plants, and associated parasitoids in the extreme north of Amapá State, Brazil. Florida Entomologist 100: 316–324.

Adaime R, Sousa MSM, Pereira JF. 2023. *Anastrepha* species and their hosts in the Brazilian Amazon. http://anastrepha.cpafap.embrapa.br (last accessed 23 Jun 2023).

Adaime R, Sousa MSM, Santos JCR, Deus EG. 2018b. Pioneer tree species as fruit flies parasitoids reservoir in the Brazilian Amazon. Biota Neotropica 18: e20170428. DOI: 10.1590/1676-0611-BN-2017-0428

Allwood AJ, Chinajariyawong A, Kritsaneepaiboon S, Drew RAI, Hamacek EL, Hancock DL, Hengsawad C, Jinapin JC, Jirasurat M, Krong CK, Leong CTS, Vijaysegaran S. 1999. Host plant records for fruit flies (Diptera: Tephritidae) in Southeast Asia. Raffles Bulletin of Zoology 47: 1–92.

Almeida RR. 2016. Dípteros (Tephritidae e Lonchaeidae) associados à produção de frutas na Ilha de Santana, Amazônia Brasileira. Dissertation, Universidade Federal do Amapá, Programa de Pós-graduação em Biodiversidade Tropical, Macapá, Brazil.

Almeida RR, Cruz KR, Sousa MSM, Costa-Neto SV, Jesus-Barros CR, Lima AL, Adaime R. 2016. Frugivorous flies (Diptera: Tephritidae, Lonchaeidae) associated with fruit production on Ilha de Santana, Brazilian Amazon. Florida Entomologist 99: 426–436.

Aluja M. 1994. Bionomics and management of *Anastrepha*. Annual Review of Entomology 39: 155–178.

Aluja M, Mangan RL. 2008. Fruit fly (Diptera: Tephritidae) host status determination: critical conceptual, methodological, and regulatory considerations. Annual Review of Entomology 53: 473–502.

Araujo MR, Uramoto K, Ferreira ENL, Mesquita Filho W, Walder JMM, Savaris M, Zucchi RA. 2018. Fruit fly (Diptera: Tephritidae) diversity and host relationships in diverse environments estimated with two sampling methods. Environmental Entomology 48: 227–233.

Belo APD, Rocha LMS, Corrêa JMG, Ferreira RMA, Costa-Neto SV, Sousa MSM, Adaime R, Lemos LN. 2020. New host plants records of *Bactrocera carambolae* Drew & Hancock, 1994 and *Anastrepha* spp. (Diptera: Tephritidae) in Brazil. Entomological Communicatons 2: ec02036. DOI: 10.37486/2675-1305.ec02036

Boni R, Novelli FZ, Silva AG. 2009. Um alerta para os riscos de bioinvasão de jaqueiras, *Artocarpus heterophyllus* Lam., na Reserva Biológica Paulo Fraga Rodrigues, antiga Reserva Biológica Duas Bocas, no Espírito Santo, Sudeste do Brasil. Natureza on line 7: 51–55.

Buffington M, Ronquist F. 2006. Familia Figitidae, pp. 829–838 *In* Fernández F, Sharkey MJ [eds.], Introducción a los Hymenoptera de la Región Neotropical. Sociedad Colombiana de Entomología y Universidad Nacional de Colombia, Bogotá, Colombia.

Canal NA, Zucchi RA. 2000. Parasitóide – Braconidae, pp. 119–126 *In* Malavasi A, Zucchi RA [eds.], Moscas-das-frutas de Importância Econômica no Brasil: Conhecimento Básico e Aplicado. Holos, São Paulo, Brazil.

Carvalho RS. 2003. Estudos de laboratório e de campo com o parasitóide exótico *Diachasmimorpha longicaudata* Ashmead (Hymenoptera: Braconidae) no Brasil. Ph.D. Thesis, Universidade de São Paulo, São Paulo, Brazil.

Chinajariyawong A, Clarke AR, Jirasurat M, Kristsaneepaiboon S, Lahey HA, Vijaysegaran S, Walter GH. 2000. Survey of Opiine parasitoids of fruit flies (Diptera: Tephritidae) in Thailand and Malaysia. The Raffles Bulletin of Zoology 48: 1–38.

Corrêa MP. 1984. Dicionário de plantas úteis do Brasil e das exóticas cultivadas. Imprensa Nacional 6: 170–171.

Costa JVTA, Sousa MSM, Souza-Filho MF, Matos AKBT, Brito CF, Costa MD, Adaime R. 2022. *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) no estado do Amapá, Brasil: registro de entrada e pressupostos para o seu não estabelecimento. Research, Society and Development 11: e291111032879. DOI: 10.33448/rsd-v11i10.32879

Creão MIP. 2003. Moscas-das-frutas (Diptera: Tephritidae): espécies, distribuição, medidas da fauna e seus parasitóides (Hymenoptera: Braconidae) no Estado do Amapá. M.S. Dissertation, Universidade do Amazonas, Instituto Nacional de Pesquisas da Amazônia, Manaus, Brazil.

Deus EG, Godoy WAC, Sousa MSM, Lopes GN, Jesus-Barros CR, Silva JG, Adaime R. 2016a. Co-infestation and spatial distribution of *Bactrocera carambolae* and *Anastrepha* spp. (Diptera: Tephritidae) in common guava in the eastern Amazon. Journal of Insect Science 16: 1–7.

Deus EG, Pinheiro LS, Lima CR, Sousa MSM, Guimarães JA, Strikis PC, Adaime R. 2013. Wild hosts of frugivorous dipterans (Tephritidae and Lonchaeidae) and associated parasitoids in the Brazilian Amazon. Florida Entomologist 96: 1621–1625.

Deus EG, Sousa MSM, Adaime R. 2016b. Taperebá, pp. 260–265 *In* Silva NM, Adaime R, Zucchi RA [eds.], Pragas Agrícolas e Florestais na Amazônia. Embrapa, Brasília, Brazil.

Drew RAI, Hancock DL. 1994. The *Bactrocera dorsalis* complex of fruit flies (Diptera: Tephritidae: Dacinae) in Asia. Bulletin of Entomological Research Supplement Series 2: 1–68.

Duarte AL, Malavasi A. 2000. Tratamento quarentenário, pp. 187–192 *In* Malavasi A, Zucchi RA [eds.], Moscas-das-frutas de Importância Econômica no Brasil: Conhecimento Básico e Aplicado. Holos, São Paulo, Brazil.

Dutra VS, Ronchi-Teles B, Garcia MVB, Adaime R, Silva JG. 2013. Native hosts and parasitoids associated with *Anastrepha fractura* and other *Anastrepha* species (Diptera: Tephritidae) in the Brazilian Amazon. Florida Entomologist 96: 270–273.

Ferreira ME, Rangel PHN. 2015. Melhoramento genético preventivo: obtenção de estoques genéticos resistentes a pragas quarentenárias de alto risco para a agricultura Brasileira, pp. 275–292 *In* Sugayama RL, Silva ML, Silva SXB, Ribeiro LC, Rangel LEP [eds.], Defesa Vegetal: Fundamentos, Ferramentas, Políticas e Perspectivas. Sociedade Brasileira de Defesa Agropecuária, Belo Horizonte, Brazil.

Ferreira RJ, Narciso CS. 2018. Notas preliminares sobre políticas públicas e espaços turísticos em Oiapoque/AP - Brasil. Revista Movimentos Sociais e Dinâmicas Espaciais 7: 158–173.

Fidalgo O, Bononi VLR. 1984. Técnicas de coleta**,** preservação e herborização de material botânico*.* Instituto de Botânica, São Paulo, Brazil.

Fletcher BS. 1989. Ecology: movements of tephritid fruit flies, pp. 209–219 *In* Robinson AS, Hooper G [eds.], Fruit Flies: their Biology, Natural Enemies and Control. Elsevier, Amsterdam, Netherlands.

Godoy MJS, Pacheco WSP, Malavasi A. 2011. Moscas-das-frutas quarentenárias para o Brasil, pp. 111–132 *In* Silva RA, Lemos WP, Zucchi RA [eds.], Moscas-das-frutas na Amazônia Brasileira: Diversidade, Hospedeiros e Inimigos Naturais. Embrapa Amapá, Macapá, Brazil.

Guimarães JA, Gallardo FE, Diaz NB, Zucchi RA. 2003. Eucoilinae species (Hymenoptera: Cynipoidea: Figitidae) parasitoids of fruit-infesting dipterous larvae in Brazil: identity, geographical distribution and host associations. Zootaxa 278: 1–23.

IBGE (Instituto Brasileiro de Geografia e Estatística). 2020. Área territorial Brasil, Grandes Regiões, Unidades de Federação e Municipios. https://www.ibge.gov.br/geociencias/organizacao-do-territorio/estrutura-territorial/15761-areas-dos-municipios.html?=&t=acesso-ao-produto (last accessed 23 Jun 2023).

Iwahashi O. 1999. Distinguishing between the two sympatric species *Bactrocera carambolae* and *B. papayae* (Diptera: Tephritidae) based on aedeagal length. Annals of the Entomological Society of America 92: 1–5.

Iwahashi O. 2000. Speciation of *Bactrocera dorsalis* complex based on aedeagal length, pp. 591–594 *In* Tan KH [ed.], Area-wide Control of Fruit Flies and Other Insect Pests, Penerbit Universiti Sains Malaysia, Penang, Malaysia.

Jagtap UB, Panaskar SN, Bapat VA. 2010. Evaluation of antioxidant capacity and phenol content in jackfruit (*Artocarpus heterophyllus* Lam.) fruit pulp. Plant Foods for Human Nutrition 65: 99–104.

Lemos LN, Adaime R, Jesus-Barros CR, Deus EG. 2014. New hosts of *Bactrocera carambolae* (Diptera: Tephritidae) in Brazil. Florida Entomologist 97: 841–847.

Lorenzi H, Lacerda MTC, Bacher LB [eds.]. 2015. Frutas no Brasil: Nativas e Exóticas (de consumo in natura). Plantarum, Nova Odessa, Brazil.

Malacrida AR, Gomulski LM, Bonizzoni M, Bertin S, Gasperi G, Guglielmino CR. 2007. Globalization and fruit fly invasion and expansion: the medfly paradigm. Genética 131: 1–9.

Malavasi A. 2000. Áreas-livres ou de baixa prevalência, pp.175–181 *In* Malavasi A, Zucchi RA [eds.], Moscas-das-frutas de Importância Econômica no Brasil: Conhecimento Básico e Aplicado. Holos, São Paulo, Brazil.

Malavasi A. 2009. Biologia, ciclo de vida, relação com o hospedeiro, espécies importantes e biogeografia de tefritídeos, pp. 1–15 *In* V Curso Internacional de Capacitação em Moscas-das-frutas, Juazeiro, Bahia, Brazil. 21–29 Oct 2009.

Malavasi A. 2015. Mosca-da-carambola, *Bactrocera carambolae* Drew & Hancock, pp. 173–184 *In* Vilela EF, Zucchi RA [eds.], Pragas Introduzidas no Brasil: Insetos e Ácaros. FEALQ, Piracicaba, Brazil.

Malavasi A, Zucchi RA, Sugayama RL. 2000. Biogeografia, pp. 93–98 *In* Malavasi A, Zucchi RA [eds.], Moscas-das-frutas de Importância Econômica no Brasil: Conhecimento Básico e Aplicado. Holos, São Paulo, Brazil.

MAPA (Ministério da Agricultura, Pecuária e Abastecimento). 2015. Nota técnica para divulgação de investimento no controle de moscas-das-frutas de 2015. Programa Nacional de Combate às Moscas-das-Frutas, Ministério da Agricultura, Pecuária e Abastecimento, Secretaria de Defesa Agropecuária, Distrito Federal, Brazil, http://www.agricultura.gov.br/combate-as-moscas-das-frutas (last accessed 22 Jan 2023).

MAPA (Ministério da Agricultura, Pecuária e Abastecimento). 2018. Instrução Normativa nº 57, de 1 de outubro de 2018. Estabelece, na forma do Anexo desta Instrução Normativa, a lista de Pragas Quarentenárias Presentes (PQP) para o Brasil. Ministério da Agricultura, Pecuária e Abastecimento, Secretaria de Defesa Agropecuária, Distrito Federal, Brazil, https://www.gov.br/agricultura/pt-br/assuntos/sanidade-animal-e-vegetal/sanidade-vegetal/arquivos-prevencao/copy2_of_portaria382018.pdf (last acessed 26 Jun 2023).

Marinho CF, Silva RA, Zucchi RA. 2011. Chave de identificação de Braconidae (Alysiinae e Opiinae) parasitoides de larvas frugívoras na região amazônica, pp. 91–102 *In* Silva RA, Lemos WP, Zucchi RA [eds.], Moscas-das-frutas na Amazônia Brasileira: Diversidade, Hospedeiros e Inimigos Naturais. Embrapa Amapá, Macapá, Brazil.

Marsaro Júnior AL, Adaime R, Ronchi-Teles B, Lima CR, Pereira PRVS. 2011. *Anastrepha* species (Diptera: Tephritidae), their hosts and parasitoids in the extreme north of Brazil. Biota Neotropica 11: 117–123.

Miranda SHG, Adami ACO. 2015. Métodos quantitativos na avaliação de risco de pragas, pp. 183–203 *In* Sugayama RL, Silva ML, Silva SXB, Ribeiro LC, Rangel LEP [eds.], Defesa Vegetal: Fundamentos, Ferramentas, Políticas e Perspectivas. Sociedade Brasileira de Defesa Agropecuária, Belo Horizonte, Brazil.

Montero DAV, Meletti LMM, Marques MOM. 2013. Fenologia do florescimento e características do perfume das flores de *Passiflora quadrangularis* L. (maracujá-melão). Revista Brasileira de Horticultura Ornamental 19: 99–106.

Morais EGF, Jesus-Barros CR, Adaime R, Lima AL, Navia D. 2016. Pragas de expressão quarentenária na Amazônia, pp. 520–559 *In* Silva NM, Adaime R, Zucchi RA [eds.], Pragas Agrícolas e Florestais na Amazônia. Embrapa, Brasília, Brazil.

Nava DE, Gonçalves RS, Nornberg SD, Scheunemann T, Grutzmacher AD. 2019. Avaliação preliminar da seletividade de inseticidas e do parasitismo de *Doryctobracon areolatus* (Hymenoptera: Braconidae) em moscas-das-frutas. Boletim de Pesquisa e Desenvolvimento, Embrapa Clima Temperado, Pelotas, Rio Grande do Sul, Brazil.

Neto FOL, Lira NF. 2022. Aspectos geográficos da orla fluvial da cidade de Oiapoque, Amapá - Brasil: diagnóstico dos impactos ambientais. Geo Universidad do Estado do Rio de Janeiro 40: e64993. DOI: 10.12957/geouerj.2022.64993

Norrbom AL, Uchôa MA. 2011. New species and records of *Anastrepha* (Diptera: Tephritidae) from Brazil. Zootaxa 2835: 61–67.

Oliveira CM, Auad AM, Mendes SM, Frizzas MR. 2013. Economic impact of exotic insect pest in Brazilian agriculture. Journal of Applied Entomology 137: 1–15.

Ovruski SM, Wharton RA, Rull J, Guillént L. 2007. *Aganaspis alujai* (Hymenoptera: Figitidae: Eucoilinae), a new species attacking *Rhagoletis* (Diptera: Tephritidae) in the Neotropical Region. Florida Entomologist 90: 626–634.

Paranhos BAJ, Barbosa FR, Haji FNP, Alencar JA, Moreira AN. 2004. Monitoramento de moscas-das-frutas e o seu manejo na fruticultura irrigada do Submédio São Francisco. Feira Nacional da Agricultura Irrigada (FENAGRI), Embrapa Semi-Árido (CPATSA), Petrolina, Brazil.

Peel MC, Finlayson BL, McMahon TA. 2007. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences 11: 1633–1644.

Prakash O, Kumar R, Mishra A, Gupta R. 2009. *Artocarpus heterophyllus* (Jackfruit): an overview. Pharmacognosy Reviews 3: 353–358.

Rios MNS, Pastore Jr. F. (Org.). 2011. Plantas da Amazônia: 450 espécies de uso geral. Universidade de Brasília, Distrito Federal, Brazil,https://repositorio.unb.br/handle/10482/35458 (last accessed 19 May 2023).

Ronchi-Teles B. 2000. Ocorrência e flutuação populacional de espécies de moscas-das-frutas e parasitóides com ênfase para o gênero *Anastrepha* (Diptera: Tephritidae) na Amazônia Brasileira. Ph.D. Thesis, Universidade Federal do Amazonas, Instituto Nacional de Pesquisas da Amazônia, Manaus, Brazil.

Ronchi-Teles B, Marsaro Júnior AL, Lovato L, Silva RA. 2008. Ocorrência de *Anastrepha zenildae* Zuchi (Diptera: Tephritidae) e seu parasitóide em frutos de *Ziziphus mauritiana* (Rhamnaceae) em Roraima, resumo 1626-1 *In* 22nd Congresso Brasileiro de Entomologia, Uberlândia, Minas Gerais, Brazil. 24–29 Aug 2008.

Ronchi-Teles B, Silva NM, Norrbom A. 1996. New records of *Anastrepha* spp. (Diptera: Tephritidae) and their hosts in Rondônia and Amapá States – Brazilian Amazônia, pp 32–33 *In* 2nd Meeting of the Working and Group of Fruit Flies of the Western Hemisphere, Viña Del Mar, Chile. 3–8 Nov 1996.

Sá TDA. 1986. Caracterização climática da Amazônia oriental, pp. 3–13 *In* Burger DM. [ed.], Pesquisas Sobre Utilização e Conservação do Solo na Amazônia Oriental. Embrapa, Belém, Brazil.

van Sauers-Muller A. 1991. An overview of the Carambola fruit fly *Bactrocera* species (Diptera: Tephritidae), found recently in Suriname. Florida Entomologist 74: 432–440.

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

Schutze MK, Aketarawong N, Amornsak W, Armstrong KF, Augustinos AA, Barr N, Bo W, Bourtzis K, Boykin LM, Cáceres C, Cameron SL, Chapman TA, Chinvinijkul S, Chomič A, De Meyer M, Drosopoulou E, Englezou A, Ekesi S, Gariou-Papalexiou A, Geib SM, Hailstones D, Hasanuzzaman M, Haymer D, Hee AKW, Hendrichs J, Jessup A, Ji Q, Khamis FM, Krosch MN, Leblanc L, Mahmood K, Malacrida AR, Mavragani-Tsipidou P, Mwatawala M, Nishida R, Ono H, Reyes J, Rubinoff D, San Jose M, Shelly TE, Srikachar S, Tan, KH, Thanaphum S, Haq I, Vijaysegaran S, Wee SL, Yesmin F, Zacharopoulou A, Clarke AR. 2014. Synonymization of key pest species within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae): taxonomic changes based on a review of 20 years of integrative morphological, molecular, cytogenetic, behavioural and chemoecological data. Systematic Entomology 40: 456–471.

Silva GV, Granger S, Tourneau FML. 2019. Desafios à circulação na fronteira entre Brasil e Guiana Francesa (França). SciELO Journals, dataset. DOI: 10.6084/m9.figshare.10296374.v1.

Silva JG, Uramoto K, Malavasi A. 1998. First Record of *Ceratitis capitata* (Diptera: Tephritidae) in the eastern Amazon, Pará, Brazil. Florida Entomologist 81: 574–577.

Silva OLR, Suman R, Silva JR. 1997. Mosca da carambola (*Bactrocera carambolae* Drew & Hancock). Alerta Quarentenário 1, Ministério da Agricultura, Pecuária e Abastecimento, Brasília, Brazil.

Silva RA, Deus EG, Raga A, Pereira JDB, Souza-Filho MF, Costa Neto SV. 2011a. Monitoramento de moscas-das-frutas na Amazônia: amostragem de frutos e uso de armadilhas, pp. 33–50 *In* Silva RA, Lemos WP, Zucchi RA [eds.], Moscas-das-frutas na Amazônia Brasileira: Diversidade, Hospedeiros e Inimigos Naturais. Embrapa Amapá, Macapá, Brazil.

Silva RA, Jordão AL, Sá LAN, Oliveira MRV. 2004. Mosca-da-carambola: uma ameaça à fruticultura brasileira. Circular Técnica 31, Embrapa Amapá, Macapá, Brazil.

Silva RA, Pereira JDB, Lemos LN, Jesus CR, Lima AL, Lima CR. 2009. Novos registros de hospedeiros de *Anastrepha striata* Schiner (Diptera: Tephritidae) no Estado do Amapá, Brasil. O Biológico 7: 137.

Sousa MSM, Adaime R, Pereira JF. 2023. Fruit fly parasitoids in the Brazilian Amazon, http://parasitoid.cpafap.embrapa.br (last accessed 23 Jun 2023).

Sousa MSM, Jesus-Barros CR, Yokomizo GK, Lima AL, Adaime R. 2016. Ocorrência de moscas-das-frutas e parasitoides em *Spondias mombin* L. em três municípios do estado do Amapá, Brasil. Biota Amazônia 6: 50–55.

Sousa MSM, Santos JCR, Jesus CR, Yokomizo GKI, Deus EG, Pereira JF, Adaime R. 2019. Goiabeiras comuns contribuem para expansão da área de distribuição de *Bactrocera carambolae* na Amazônia Brasileira, pp. 196–206 *In* Pacheco JTR, Kawanishi JY, Nascimento R [orgs.], Meio Ambiente e Desenvolvimento Sustentável, Atena, Paraná, Brazil.

Sousa MSM, Santos JEV, Nava DE, Zucchi RA, Adaime R. 2021. Overview and checklist of parasitoids (Hymenoptera, Braconidae and Figitidae) of *Anastrepha* fruit flies (Diptera, Tephritidae) in the Brazilian Amazon. Annual Research & Review in Biology 36: 60–74.

Souza VC, Lorenzi H. 2019. Botânica Sistemática: Guia Ilustrado para Identificação das Famílias de Fanerógamas Nativas e Exóticas no Brasil, Baseado em APG IV, 4 edition. Jardim Botânico Plantarum, São Paulo, Brazil.

Trindade RBR, Uchoa MA. 2011. Species of fruit flies (Diptera: Tephritidae) in a transect of the Amazonian Rainforest in Oiapoque, Amapá, Brazil. Revista Zoologia 28: 653–657.

Vayssières JF, Cayol JP, Chambaud M, Blanc M. 2003. Degré d'infestation de différentes espèces fruitières par les Tephritidae en Guyane française et pourcentage de parasitisme des espèces de Tephritidae d'intérêt économique, pp. 11–18 *In* XIV Colloque de Physiologie de l'Insecte, University of Picardie Jules Verne, France. 14–16 Apr 2003.

Vayssières JF, Cayol JP, Caplong P, Séguret J, Midgarden D, van Sauers-Müller A, Zucchi R, Uramoto K, Malavasi A. 2013. Diversity of fruit fly (Diptera: Tephritidae) species in French Guiana: their main host plants and associated parasitoids during the period 1994-2003 and prospects for management. Fruits 68: 219–243.

Wee S-L, Tan K-H. 2005. Evidence of natural hybridization between two sympatric sibling species of *Bactrocera dorsalis* complex based on pheromone analysis. Journal of Chemical Ecology 31: 845–858.

WFO (World Flora Online). 2023. The World Flora Online, http://www.worldfloraonline.org (last accessed 23 Jun 2023).

White IM, Elson-Harris M [eds.]. 1992. Fruit Flies of Economic Significance: Their Identification and Bionomics. CAB International/ACIAR, Wallingford, United Kingdom.

Zucchi RA, Moraes RCB. 2023. Fruit flies (Diptera: Tephritidae) in Brazil - *Anastrepha* species their host plants and parasitoids. http://www.lea.esalq.usp.br/anastrepha (last accessed 21 Jan 2023).

Zucchi RA, Uramoto K, Souza-Filho MF. 2011. Chave ilustrada para as espécies de *Anastrepha* da região Amazônica, pp. 71–90 *In* Silva RA, Lemos WP, Zucchi RA [eds.], Moscas-das-frutas na Amazônia Brasileira: Diversidade, Hospedeiros e Inimigos Naturais. Embrapa Amapá, Macapá, Brazil.