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Tritrophic relations and spatial distribution of fruit flies (Diptera: Tephritidae) in the Cerrado and Caatinga regions in Piauí, Brazil

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ABSTRACT

Knowledge about the spatial distribution of fruit flies (Diptera: Tephritidae) and tritrophic interactions (fruit-fruit fly parasitoid) contributes to the monitoring and maintenance of the numerical density at a level lower than economic damage. The purpose of this study was to identify the spatial distribution and associations of fruit flies with their parasitoids and host plants in the municipality of Bom Jesus-PI. The flies were obtained from fruit collection from July 2018 to May 2019. A total of 1,711 individuals were obtained, represented by six species: *Anastrepha obliqua* (Macquart, 1835), *An. fraterculus* (Wiedemann, 1830), *An. alveata* Stone, 1942, *An. sororcula* Zucchi, 1979, *An. zenildae* Zucchi, 1979 and *Ceratitis capitata* (Wiedemann, 1824). *Anastrepha obliqua* was the species with the widest distribution throughout the ecotone area. *Ceratitis capitata* is distributed only in the urban perimeter. A tritrophic relationship occurred between four species of parasitoids, *Asobara anastrephae* (Muesebeck, 1958) or *Opius* sp. associated with *An. obliqua* in *Spondias mombin* or *S. tuberosa* fruits. *Opius* sp. has also been associated with *An. alveata* in *Ximenia americana*. *Pachycrepoideus vindemiae* was obtained from *C. capitata* in *Malpighia emarginata*, in addition to *An. obliqua* in *Averrhoa carambola*. Therefore, fruit flies are associated with native fruit trees (*S. tuberosa*, *S. mombin, S. purpurea*, *P. acutangulum, Inga laurina*, *X. americana*) and exotic fruits (*M. emarginata*, *A. carambola*, *P. guajava*). *Ceratitis capitata* was recorded for the first time in the state of Piauí infesting *I. laurina* (Sw.) Willd. This is the first record of the parasitoid genus *Spalangia*. in *An. obliqua* in Piauí and in the semiarid region of Brazil.

Introduction

Knowledge about the tritrophic relations and spatial distribution of insects provides a basis for defining the management strategy of insect populations of economic importance (Soberón, 2010; Teixeira et al., 2021). The interactions involving fruit flies and parasitoids have been largely studied worldwide due to their economic importance and the possibility of using their parasitoids as biological control agents, and the study of interactions between insects and fruits is one of the main challenges for understanding the reproductive success of many angiosperms because the damage caused by insects can cause loss of productivity in a wide variety of fruits. Fruit-eating insects can influence the production due to direct damage and by indirect damage through biochemical changes that cause premature ripening of the fruit or increased protein levels (Aluja, 1999; Ovruski et al., 2000, 2004; Schliserman et al., 2016; López-Ortega et al., 2020). Fruit flies of the Tephritidae family are among the most harmful insects to commercial fruits because the larval stage develops within the fruit (Garcia et al., 2017).

Studies evaluating the population distribution of fruit flies associated with host plants are useful to understand the real biotic potential of these species (Zucchi, 2000; Midgarden et al., 2014; Enkerlin et al., 2015; Arbab and Mirphakhar, 2016; Nicácio et al., 2019; Teixeira et al., 2021). It is important to understand these introductions in ecotonal areas, whose relationships are mixed and with high structural complexity, provide locational and behavioral information for insect management tactics of economic importance (Costa-Coutinho et al., 2019).

One of the main forms of control of fruit flies is the use of integrated insect management. However, to establish this sustainable system, it is essential to know the natural enemies as their parasitoids, especially Hymenoptera, considered by many researchers to be the most efficient natural enemies of fruit flies in various parts of the world (Aluja et al., 2014). The composition of parasitoid species in a region can vary

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considerably, depending on several factors, such as climate, fruit fly species diversity, and infested fruit trees (Araujo et al., 2015). Information on the diversity and geographical distribution of parasitoids and their hosts is scarce in fragmented ecotonal habitats.

In Piauí, the most recent reports include 23 described species of *Anastrepha* (Zucchi and Moraes, 2022); for the city of Bom Jesus, however, there is currently one known species of *Anastrepha* in addition to *C. capitata* (Coelho et al., 2020). There is only one article published, which was carried out in the urban area of Bom Jesus on the occurrence of fruit fly parasitoid species (Coelho et al., 2020). The identification of native parasitoids requires an intensive analysis of native and exotic fruits in order to verify the association between fly and parasitoid species and their host plants (Silva et al., 2010; Deus et al., 2013).

The aim of this study was to evaluate the interaction of fruit flies with their parasitoids in host plants and their distribution in the municipality of Bom Jesus-state Piaui, Brazil, which has Cerrado, Caatinga vegetation, and transition vegetation (Ecotonal).

Materials and methods

Study area

This study was conducted from July 2018 to May 2019 in the municipality of Bom Jesus-Piauí Brazil (09°04'28 " S, 44°21'31 " W; 277 m), which integrates the Piauí semiarid region (Fig. 1). It has a territory of 5,469 km^2. The climate is warm and humid, classified by Köppen as Awa, tropical rain with a dry season in winter, with average rainfall between 900 and 1.200 mm/year-1 and average temperature of 26.2 °C (INMET, 2019).

In this region, the high spatial and environmental heterogeneity presents itself as a complex mosaic of vegetation types, ranging from the driest, such as the Caatinga, with small vegetation, trees and thorny shrubs, in addition to Cactaceae, Euphorbiaceae, Bromeliaceae, and Fabaceae plants adapted to withstand water deficit. It has areas of Cerrado, with large shrubs and sparse trees, with twisted branches and deep roots (Souza et al., 2017; Costa-Coutinho et al., 2019). It includes a wide range of Cerrado-Caatinga transition vegetation due to environmental heterogeneity, and its vegetation cover forms a complex mosaic of vegetation types (Macedo et al., 2019). In the transition vegetation ecotone area, there is a current of the Matões Stream microbasin and the Gurguéia River Basin, with riparian forest throughout its course (Paula Filho et al., 2012).

For interpretation purposes, the collected areas were subdivided into: Caatinga - a region of difficult access where the Viana Canyons (rock formations) are located, bordering the Serra das Confusões; Cerrado - a region with intense expansion of deforestation, where the main cultivation areas (soybean, corn) are located; transition vegetation (Ecotone) - central strip of the municipality with the current of the Matões stream, Gurguéia River and the urban perimeter (Fig. 1). Inventory regarding fruit fly species in this region are still scarce (Araújo et al., 2014; Coelho et al., 2018; Vieira et al., 2019; Coelho et al., 2020).

Fruit collection

The fruits were collected weekly at different points in the municipality, which were georeferenced (we tried to cover the entire area of the municipality, excluding areas of difficult access). The fruits were collected according to availability at each point, and each point was sampled only once. Each plant species, georeferenced, from a total of 27 sampled, was named by a numeral to facilitate its spatial identification on the map (Fig. 1).

The fruits were placed in plastic trays and transported to the Plant Protection Laboratory of the Federal University of Piauí (UFPI/CPCE), quantified, weighed individually, labeled and placed in plastic containers containing autoclaved sand and closed. The trays were kept in a room at room temperature (25 ± 2 °C and 70 ± 5% RH). The fruits and sand were sorted between 10 and 15 days, and the pupae were transferred to transparent plastic cups containing sterilized sand for adult emergence for a period of 20 days. The emerged insects were placed in properly labeled glass vials containing 70% ethanol for subsequent identification.

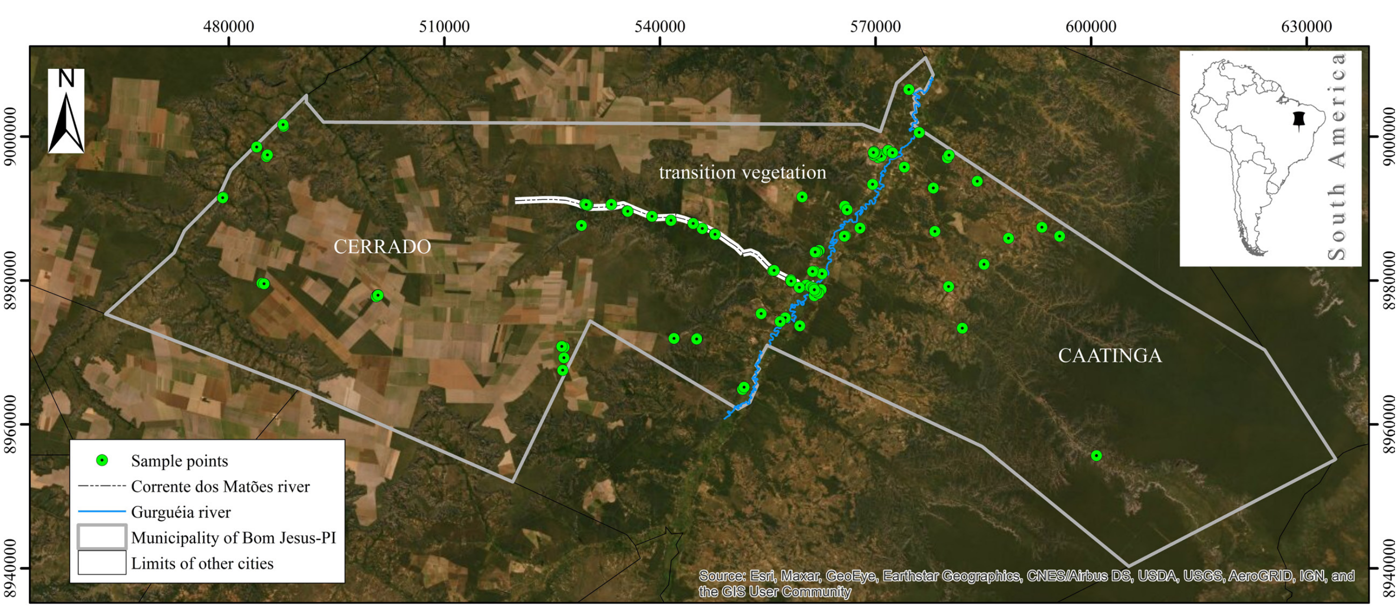

Figure 1 Inventory area on fruit flies, showing the distribution of sampling points and the main characteristic environments of the region in the municipality of Bom Jesus-PI, July 2018 to May 2019.

Identification of fruit flies, parasitoids, and host plants

The fruit flies were identified based on the morphological characteristics of the females, mainly in the ventral examination of the aculeus, according to Zucchi (2000).

The parasitoids were identified by morphological characteristics, such as coloration of the antenna apex, tibia, and mandibles, by the researcher Dr. Jorge Anderson Guimaraes from Embrapa de Hortaliças - DF. The specimens of fruit flies and parasitoids were deposited in the Zoology Laboratory of the Federal University of Piauí (UFPI/CPCE).

For the identification of plant species, branches containing reproductive structures (flowers and fruits) were collected. The material was kept as complete as possible and subsequently herborized. According to usual assembly and preservation techniques (Mori et al., 1989; Judd et al., 2009). Plant identification was performed by Prof. Dr. Marcelo Sousa Lopes, Federal University of Piauí-UFPI/CPCE. The identification of unknown individuals was provided through the collection of the Graziela Barroso Herbarium (TEPB), as well as the INCT (2019) website, using analytical keys (Joly, 1975; Barroso, 1984; Luz et al., 2020).

The classification system adopted for the plants was that of APG IV (2016) and abbreviation of the names of the authors of the species, following the same method used on the website of the Botanical Garden of Rio de Janeiro (The Brazil Flora Group, 2018). After proper identification, the specimens were recorded in the SISGEN (National System of Management of Genetic Heritage and Associated Traditional Knowledge) taxon database, as well as in the collection of exsiccates from the herbarium of the UFPI Campus in Bom Jesus and Teresina.

Data analysis

Each sampled group of fruits of each species was weighted. For each sample, fruit infestation levels were calculated by dividing the total number of pupae obtained from the fruit sample by its total weight. The indexes of infestation by flies and of parasitism were obtained by dividing the total number of adult flies and/or parasitoids that emerged from the pupae by the total number of pupae obtained from the sample and multiplied by 100.

The spatial distribution patterns of the fruit fly species were evaluated by the Voronoi Diagram method, which is a partition of a plane into regions close to each of a given set of objects. In the simplest case, these objects are just a finite number of points in the plane (called plants, sites, or generators). For each plant, there is a corresponding region called a Voronoi cell, which consists of all points in the plane closer to that plant than to any other. The Voronoi diagram of a set of points is dual to its Delaunay triangulation. (Feng and Murray, 2018). A map was generated with the definitions of the areas at each sampling point for each variable analyzed. The cross-summation of the factors in the map determined the locations of occurrence of fruit flies, parasitoids,

Table 1
Fruit flies (Diptera: Tephritidae), parasitoids (Hymenoptera) and host fruit trees (native and exotic) sampled in different environments of the municipality of Bom Jesus-PI (July 2018 to May 2019).

Plant Families	Plant Species	Sample Weight (Kg)	Infested Fruit Yes/No	Species of fruit flies	Species of parasitoids	Occurrence Environments
Anacardiaceae	*Spondias purpurea*	1.43	Yes	*Anastrepha obliqua* *Ceratitis capitata*	- -	Transition Vegetation
	Spondias tuberosa	3.55	Yes	*Anastrepha obliqua*	*Asobara anastrephae* *Opius* sp.	Transition Vegetation
	Spondias mombin	7.17	Yes	*Anastrepha obliqua*	*Asobara anastrephae* *Opius* sp.	Transition Vegetation
	Anacardium occidentale	22.50	Yes	*Anastrepha obliqua*	- -	Transition Vegetatione
	Mangifera indica	0.21	No	- -	- -	Transition Vegetation
Apocynaceae	*Hancornia speciosa*	0.02	No	- -	- -	Cerrado
Annonaceae	*Annona squamosa*	0.02	No	- -	- -	Cerrado
Cactaceae	*Cereus jamacaru*	0.13	No	- -	- -	Transition Vegetation
	Cereus gounellei	0.14	No	- -	- -	Transition Vegetation
Euphorbiaceae	*Manihot piauhyensis*	0.47	No	- -	- -	Cerrado
Fabaceae	*Inga laurina*	0.23	Yes	*Ceratitis capitata*	- -	Transition Vegetation
	Andira sp.	0.61	Yes	*Anastrepha zenildae*	- -	Transition Vegetation
	Dipteryx lacunifera	0.10	No	- -	- -	Cerrado
	Copaifera langsdorffii	0.02	No	- -	- -	Cerrado
Myrtaceae	*Psidium guajava*	7.56	Yes	*Anastrepha fraterculus*	- -	Transition Vegetation
	Psidium acutangulum	12.39	Yes	*Anastrepha sororcula* *Anastrepha fraterculus*	- -	Transition Vegetation
	Psidium sp.	0.56	No	- -	- -	Caatinga
Malpigiaceae	*Malpighia emarginata*	4.80	Yes	*Ceratitis capitata*	*Pachycrepoideus vindemiae*	Transition Vegetation
Malvaceae	*Guazuma ulmifolia*	0.02	No	- -	- -	Cerrado
Melastomataceae	*Mouriri pusa*	1.51	Yes	*Anastrepha fraterculus*	- -	Transition Vegetation
	Muriri elliptica	0.19	No	- -	- -	Cerrado
Rubiaceae	*Tocoyena sp.*	2.20	No	- -	- -	Cerrado
	Alibertia edulis	2.64	No	- -	- -	Cerrado
Rutaceae	*Citrus sinensis*	1.28	No	- -	- -	Transition Vegetation
Solanonaceae	*Physalis angulata*	0.01	No	- -	- -	Transition Vegetation
Olacaceae	*Ximenia americana*	1.75	Yes	*Anastrepha alveata*	*Opius* sp.	Transition Vegetation
Oxalidaceae	*Averrhoa carambola*	1.81	Yes	*Ceratitis capitata* *Anastrepha obliqua*	- - *Pachycrepoideus vindemiae* *Spalangia* sp.	Transition Vegetation

host plants and the relationship between them using *ArcGis software* (Esri Inc, 2020).

Results

Fruit fly host plant interactions

We examined fruit samples from 27 plant species of 15 botanical families, which summed to a total of 73,333 Kg. We documented the presence of five species of the genus *Anastrepha* infesting 10 fruit species belonging to seven families and the presence of *C. capitata* infesting four fruit species belonging to four families (Table 1).

Of the fruit flies sampled, *An. obliqua*, and *C. capitata* had greater infestation rates. The least representative species were *An. alveata* and *An. zenildae*. The plants with the highest occurrence of the collected fruit fly species were *Malpighia emarginata*, *Spondias mombin* and *S. tuberosa* (Table 2). Of the fruit flies, *An. obliqua* had a frequency of 45.7%, and *Ceratitis capitata* had a frequency of 39.3%. The other species had a low percentage of occurrence during the collections, with *An. fraterculus* (2.8%), *An. sororcula* (1.5%), *An. alveata* (1.1%) and *An. zenildae* (0.5%).

Our sampling efforts resulted in the first records of *C. capitata* infesting *Inga laurina* in the state of Piauí.

Anastrepha obliqua was widely distributed: *S. mombin* L., *S. tuberosa* L., *Averrhoa carambola* L., *Anacardium occidentale* L., *S. purpurea* L. and *Psidium guajava* L. (Figs. 2B and 2A). The other species of fruit flies occurred at restricted sites: *An. zenildae* in an area of Cerrado, infesting *Andira* sp.; *An. sororcula* in the transition vegetation (ecotonal), infesting

Table 2
Abundance of species of fruit flies (Diptera: Tephritidae) sampled in native and exotic hosts (municipality of Bom Jesus-PI, July 2018 to May 2019).

Fruit plants	*C. capitata*	*An. alveata*	*An. fraterculus*	*An. obliqua*	*An. sororcula*	*An. zenildae*	Total
Malpighia emarginata	461(5)	- -	- -	- -	- -	- -	461
Ximenia americana	- -	22(2)	- -	- -	- -	- -	22
Psidium acutangulum	- -	- -	19(1)	- -	10(2)	- -	29
Spondias mombin	- -	- -	- -	412(13)	- -	- -	412
Anacardium occidentale	- -	- -	- -	3(1)	- -	- -	3
Averrhoa carambola	160(3)	- -	- -	29(2)	- -	- -	189
Psidium guajava	- -	- -	5(1)	- -	- -	- -	5
Inga laurine	11(1)	- -	- -	- -	- -	- -	11
Mouriri pusa	- -	- -	24(2)	- -	- -	- -	24
Andira sp.	- -	- -	- -	- -	- -	3(1)	3
Spondias purpurea	106(2)	- -	- -	57(2)	- -	- -	163
Spondias tuberosa	- -	- -	- -	389(4)	- -	- -	389
Grand Total	738	22	48	890	10	3	1711
No. of infested hosts	4	1	3	5	1	1	-
Infestation rates	1.0236	0,0172	0.9978	3.045	1.970	0.0064	- -

( ) = frequency in which it occurred

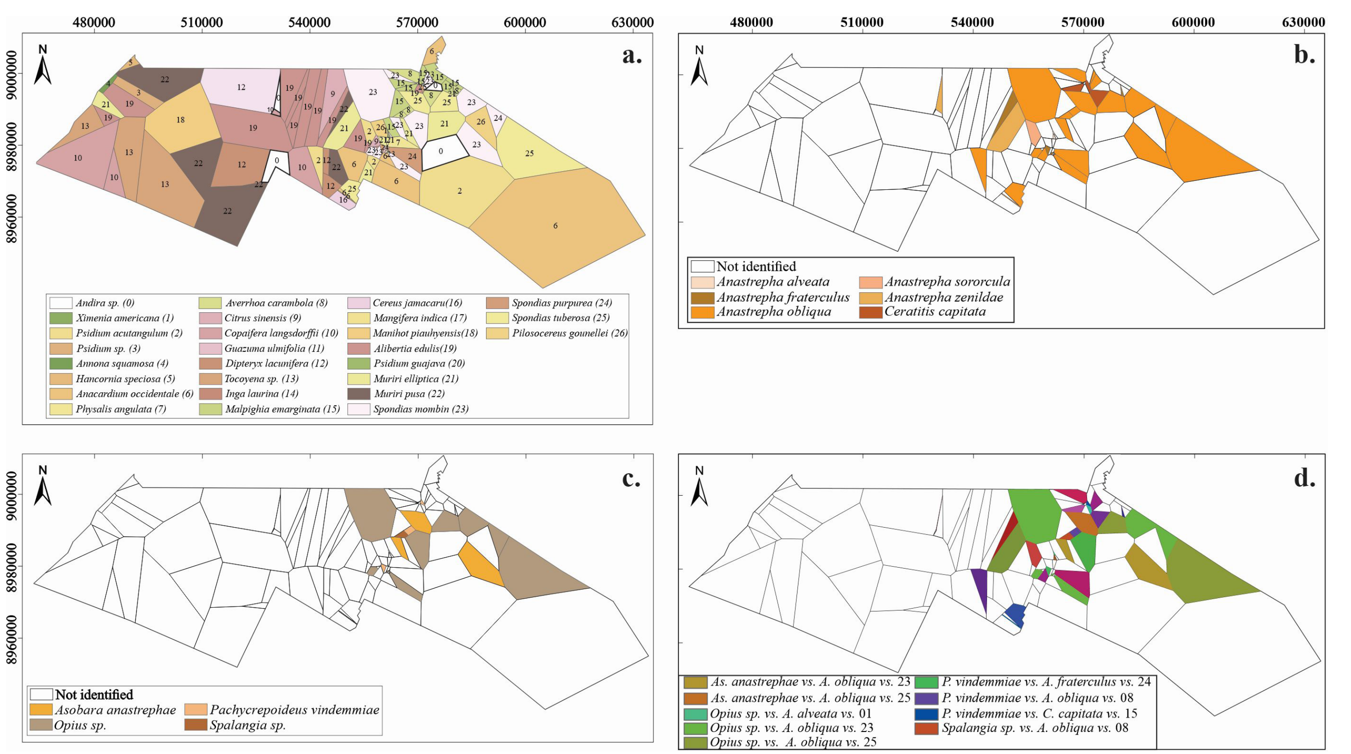

Figure 2 (A) Spatial distribution of fruit plants, (B) fruit flies (Diptera: Tephritidae), (C) parasitoids Hymenoptera and (D) tritrophic relationship in sampling of native and exotic fruits (municipality of Bom Jesus -PI, July 2018 to May 2019).

P. acutangulum DC.; *An. alveata* in the transition vegetation, infesting *Xinemia americana* L. *Anastrepha fraterculus* was obtained from three fruit species: *Mouriri pusa*, *P. acutangulum* and *P. guajava*, all in the transition vegetation (Figs. 2A and 2B). Of all the fruit fly species, *An. obliqua* exhibited the highest number of hosts in the region, exploiting up to five host species.

With respect to host plant phenology, the highest availability of fruits was generally observed in the period of August and September 2018 and February and March 2019 (8 species), with the highest number and abundance of fruits recorded during March. We observed that the fruits of *A. occidentale* were the most abundant, but only with the record of *An. abliqua*, already *S. purpurea*, with a lower amount of fruit, we recorded three species of fruit flies (Tables 1 and 3).

Anastrepha obliqua occurred from August 2018, with predominance in the months of January to April 2019 and higher population density in March due to the increased availability of *S. mombin* and *S. tuberosa* fruits in the host plants, a consequence of rainfall accumulation. in this period of the year. *Anastrepha fraterculus* occurred in November, January and March. *Ceratitis capitata* occurred in August, September and October 2018 and January to April 2019, and in August, there was a greater number of individuals collected from *M. emarginata* and *A. carambola* plants (Table 3).

Fruit infestation and parasitism rates

Fruit infestation rates were highly variable between the different hosts, ranging between 0.006 and 3.04 fruit flies/kg of sampled fruit. The highest infestation levels occurred in *M. emarginata, S. tuberosa* and *S. mombin, and* the lowest infestation rate was observed in *Andira* sp.

Four species of parasitoids associated with fruit flies were identified: *Asobara anastrephae* Muesebeck, 1958 (Hymenoptera: Braconidae) *Opius* sp. (Hymenoptera: Braconidae), *Pachycrepoideus vindemiae* Rondani, 1875 (Hymenoptera: Pteromalidae) and *Spalangia* sp. (Hymenoptera: Pteromalidae), (Table 1 and Table 4). Among these species, *Opius* sp. and *As. anastrephae* occurred in the transition vegetation and Caatinga area. The other species were distributed in transition vegetation (Fig. 2C). The occurrence of parasitoids was more restricted to the transition vegetation in the vicinity of the Gurguéia River basin and the current of the Matões stream, located in the ecotonal region (Fig. 2C).

Of the parasitoid species, the parasitism percentage were 3.24%. and 1.8% for *As. anastrephae.* The other species presented a low frequency, *Spalangia* sp. (0.13%) and *P. vindemiae* (0.19%). The fruit hosts of fruit flies with greater association with parasitoids, were *S. purpurea* and *S. monbin* and *A. carambola* in *An. Obliqua* (Table 1 and Table 4). In the case of species *An. sororcula*, *An. zenilde* and *An. fraterculus*, we did not observe any parasitism.

Table 3

Distribution of the fructification period of plant species sampled from the municipality of Bom Jesus state Piauí, Brazil. (July 2018 - May 2019). Darker shading indicates greater availability of fruits; lighter shading denotes a decrease in fruit availability, generally occurring before and after the rainy season. Asterisks indicate new host plant records for fruit flies.

Host Family	Host Scientific Name	Fruit Fly Species	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Anacardiaceae	*Spondias purpurea*	*Anastrepha obliqua*											
		Anastrepha fraterculus											
		Ceratitis capitata											
	Spondias tuberosa	*Anastrepha obliqua*											
	Spondias mombin	*Anastrepha obliqua*											
	Anacardium occidentale	*Anastrepha obliqua*											
	Mangifera indica	- -											
		- -											
Apocynaceae	*Hancornia speciosa*	- -											
Annonaceae	*Annona squamosa*	- -											
Cactaceae	*Cereus jamacaru*	- -											
	Cereus gounellei	- -											
Euphorbiaceae	*Manihot piauhyensis*	- -											
Fabaceae	*Inga laurina**	*Ceratitis capitata*											
	Andira sp.*	*Anastrepha zenildae*											
	Dipteryx lacunifera	- -											
	Copaifera langsdorffii	- -											
Myrtaceae	*Psidium guajava*	*Anastrepha fraterculus*											
		Anastrepha obliqua											
	Psidium acutangulum	*Anastrepha sororcula*											
		Anastrepha fraterculus											
	Psidium sp.	- -											
Malpigiaceae	*Malpighia emarginata*	*Ceratitis capitata*											
Malvaceae	*Guazuma ulmifolia*	- -											
Melastomataceae	*Mouriri pusa*	*Anastrepha fraterculus*											
	Muriri elliptica	- -											
Rubiaceae	*Tocoyena sp.*	- -											
	Alibertia edulis	- -											
Rutaceae	*Citrus sinensis*	- -											
Solanonaceae	*Physalis angulata*	- -											
Olacaceae	*Ximenia americana*	*Anastrepha alveata*											
Oxalidaceae	*Averrhoa carambola*	*Ceratitis capitata*											
		Anastrepha obliqua											

Table 4
Parasitoid species and levels of parasitism of fruit fly species in their hosts sampled from the municipality of Bom Jesus state Piauí, Brazil. (July 2018 - May 2019).

Family	Host Plant	Fruit fly species	Recovered Fruit Fly Pupae	Parasitoid Species	Total No. Parasitoids	% Parasitism
Anacardiaceae	*Spondias tuberosa*	*Anastrepha obliqua*	474	*Asobara anastrephae*	28	1.8
				Opius sp.	12	0.78
	Spondias mombin	*Anastrepha obliqua*	690	*Asobara anastrephae*	51	3.24
				Opius sp.	64	4.03
Malpigiaceae	*Malpighia emarginata*	*Ceratitis capitata*	161	*Pachycrepoideus vindemiae*	10	0.65
Olacaceae	*Ximenia americana*	*Anastrepha alveata*	163	*Opius* sp.	12	0.78
Oxalidaceae	*Averrhoa carambola*	*Anastrepha obliqua*	34	*Pachycrepoideus vindemiae*	3	0.19
				Spalangia sp.	2	0.13

Tritrophic interactions: fruit flies, parasitoids, and host plants

Of the parasitoid species, *As. anastrephae* is restricted to *An. obliqua* collected from *S. mombin* and *S. tuberosa* plants; *Opius* sp. occurred in *An. obliqua* in fruits of *S. mombin* and *S. tuberosa* and in *An. alveata* associated with *X. americana*; *Spalangia* sp. occurred only in *An. obliqua* in *A. carambola* fruits; *P. vindemiae* was recorded in *C. capitata*, in fruits of *M. emarginata*, and *An. obliqua* in *S. purpurea*. Of the four parasitoid species recorded, all parasitized *An. obliqua,* two of which were obtained from the same host plants: *As. anastrephae* and *Opius* sp. in *S. mombin* and *Spalangia* sp. and *P. vindemiae* in *A. carambola* fruits (Table 1 and Fig. 2D).

Of the twenty-seven (27) fruit trees sampled, twelve (12) were colonized by fruit flies. Of these, eight (8) were infested exclusively by *Anastrepha* species, and two (2) were infested exclusively by *C. capitata. Malpighia emarginata* and *A. carambola* are introduced fruit plants, while *S. purpurea* and *I. laurina* are native. Anacardiaceae had the highest number of species with infested fruits, followed by Myrtaceae and Malpighiaceae (Table 1).

Discussion

Previous studies reported 128 species of *Anastrepha* in Brazil, of which 23 species are recorded from the state of Piauí (Zucchi and Moraes, 2022); for the city of Bom Jesus, however, there are currently one known species of *Anastrepha* (*An. obliqua*) in addition to *C. capitata* (Coelho et al., 2020).

The distribution of fruit flies was more frequent in the transition vegetation area (ecotone) (Figs. 1 and 2B), which is related to the occurrence of different fruit plants, some of which are considered the preferred host of fruit flies, such as *S. mombin* (Sousa et al., 2017). This area is characterized by being a humid region due to the presence of the Gurguéia River and the Current of the Matões stream, consequently providing a greater availability of resources. Fruit flies occur in different fruit trees, such as *A. carambola* and *S. tuberosa*, which are considered endemic plants of the Caatinga (Santos et al., 2012).

Fruit flies have a relationship closely linked to the hosts of certain plant taxa. Anacardiaceae fruits, for example, have been reported as preferential hosts of *An. obliqua*. Species of this family have fruits rich in nutrients, which probably provide a higher nutritional quality for *An. obliqua* larvae. The production period (fruits), for example, of *S. mombin,* occurs between the months of February and June (Araujo et al., 2005; Souza et al., 2006), which may explain the greater abundance of this fruit flies infesting these hosts in this study due to its soon fruiting period, providing the development of the life cycle of these flies.

This preference of *An. obliqua* for fruit trees of the genus *Spondias* is not restricted to the state of Piauí (Araújo et al., 2014) but was also reported in other states and geographic regions of Brazil, such as Rio de Janeiro (Leal et al., 2009), Minas Gerais (Pirovani et al., 2010), Bahia (Bittencourt et al., 2012), Mato Grosso do Sul (Uchôa-Fernandes et al., 2002) and Amapá (Deus and Adaime, 2013).

The distribution of *C. capitata* (Mediterranean fly or medfly) was restricted to the urban perimeter of the municipality of Bom Jesus Piauí, associated with four fruit species. This species is a key pest in fruit crops in many tropical, subtropical, and temperate areas. It was possible to observe *C. capitata* infestation in *M. emarginata* and *A. carambola* but also infested native fruits, *S. purpurea* and *I. laurina*. This shows the high adaptive capacity of this species and is in constant population increase due to the invasion of new geographic areas, infesting different hosts (Zucchi and Moraes 2012; Sciarretta et al., 2018). In Piauí, there is a record of this species in *A. carambola* fruits (Feitosa et al., 2007), *S. mombin* (Araújo et al., 2014) and *S. purpurea* (Coelho et al., 2020). *Ceratitis capitata* was recorded for the first time in *I. laurina* pods in the state of Piauí. Inga fruits were sampled in an urban area (riparian forest). The family Fabaceae is widely distributed in Brazil, from the states of the Amazon to Paraná, as well as in other parts of South America, Central America, and the Caribbean Islands. *Inga laurina* was recorded as a host of *An. distincta* (Uramoto et al., 2008) and *An. striata* (Souza et al., 2018).

In the urban area, transition vegetation, of the sampled region, there are several species of fruit trees, used both in the afforestation of the city and cultivated in backyards. These sites become a reservoir of *C. capitata*, favoring its population increase. According to Alvarenga et al. (2009), in urban orchards, fruits maturing in different seasons of the year provide excellent food conditions for fruit flies, enabling the dispersal and exploitation of different niches (Alvarenga et al., 2009).

In studies on *P. guajava* plantations, Lopes et al. (2015) observed that *C. capitata* did not coexist with *Anastrepha* species. In this study, the occurrence of *C. capitata* in native fruit trees in both *S. purpurea* and *I. laurina* was observed, which shows the aggressiveness and adaptation of this species in search of new hosts. The presence of *C. capitata* in urban areas is related to urbanization, where there is a greater presence of introduced fruits, favoring the presence of this species, which competes directly with *Anastrepha* species for resources (Garcia et al., 2017). However, the correct management of native plant species that serve as natural reservoirs of fruit flies is necessary, which is essential to avoid the displacement of their populations to commercial orchards.

The *Opius* genus is one of the largest in the Braconidae family, and all opiine braconids are koinobiont endoparasitoids of Cyclorrhapha diptera, has the potential to reduce the populations of fruit flies is a genus of parasitoids that predominates in areas of native vegetation (Costa et al., 2009). Most likely, the characteristics of host plants (Anacardiaceae) favored parasitism by native parasitoids in *Anastrepha* species. López-Ortega et al. (2020) report *Opius hirtus* (Fisher) in five new fruit fly-parasitoid associations, all occurring in native tree species infested by different fly species. This highlights the preference of this parasitoid for monophagous fly species attacking comparatively small-sized fruits.

Asobara anastrephae obtained from *An. obliqua* in *S. tuberosa* and *S. mombin* fruits; *Opius* sp. obtained from *An. alveata* associated with *X. americana* and *An. obliqua* associated with *S. tuberosa* and *S. mombin*, both parasitoid species are native and have small ovipositors, which favors success in their parasitism in smaller fruits with shallow pulps (Zucchi, 2000; Sousa et al., 2016).

In addition, we document the first report of *Spalangia* sp. parasitizing *An. obliqua* in the State Piaui. The occurrence of *Spalangia* sp. in this survey shows that these parasitoids can be common in semiarid environment. Species of parasitoids of the genus *Spalandia* are generalists and parasitize pupae of various dipteran families, such as Muscidae, Calliphoridae, Sarcophagidae, Drosophilidae, and Tephritidae. In Brazil, there are records of *Spalangia* parasitizing *Anastrepha* in the southeastern and center-west regions and parasitizing *C. capitata* in the semiarid region of Brazil (Uchôa-Fernandes et al., 2003; Gibson, 2009; Nicácio et al, 2011; Beitia et al., 2016; Silva et al., 2020). Therefore, these are the first reports of *Spalangia* sp. species associated with *An. obliqua* in a semiarid region of Brazil.

Based on the observed associations, further studies should be conducted on the diversity of parasitoid species that attack fruit flies in southwestern Piauí. Future research should focus on the biology and ecology of these parasitoids, which are promising biological control agents of fruit flies. Parasitism in frugivorous tephritid larvae is quite variable in natural environments (Nicácio et al., 2011). It can be affected by several factors, such as the occurrence of host frugivorous larvae and host fruit characteristics.

Asobara anastrephae was associated with *An. obliqua* in *S. tuberosa* and *S. mombin* fruits. This species has been reported by other authors parasitizing tephritid species in Brazil (Uchôa-Fernandes et al., 2003) and in the semiarid region in a study by Sá et al. (2012), parasitizing *Anastrepha* species in *S. tuberosa* fruits, corroborating what was observed in this study. *Asobara anastrephae* is considered a species adapted to the northeast region and to several native hosts, such as umbuzeiro, endemic to the Caatinga. This parasitoid was also observed attacking the same species *An. obliqua* in the Amazon region in *S. mombin* fruits (Sousa et al., 2016).

Studies on the tritrophic interactions between fruit flies, their host plants and parasitoids are scarce. The results described here contribute to the understanding of the relationships between native parasitoids and species of fruit flies. Parasitoids are particularly important because of interactions for long periods of time with their hosts and may be effective in reducing pest populations in orchards, keeping the outbreaks of Tephritidae under control without decreasing local biodiversity (Sugayama and Malavasi, 2000; Zucchi, 2000; Uchôa-Fernandes et al., 2003; Cancino et al., 2009; Araujo et al., 2015).

This study was conducted in an ecotonal region, which has a heterogeneity of microenvironments, and the vegetation cover has a floristic mixture, where species from the Cerrado and Caatinga biomes coexist (Souza et al., 2017), with greater availability of resources for fruit flies in the ecotone area (Garcia et al., 2017). *S. tuberosa*, for example, is endemic to the Caatinga biome (Santos et al., 2012), and *M. pusa* is characteristic of Cerrado regions (Borges, 2012). Other host fruit trees in this region, such as *P. guajava, A. occidentales, P. acutangulum,* wild *X. americana*, *S. mombin*, and *S. purpurea*, were all infested by species of the genus *Anastrepha*.

Fruit flies can persist in different types of environments. Generalist species can thrive in a matrix of human use with commercial and backyard fruit orchards, while a part of the population remains and survives within the natural forest. This would be the case for *C. capitata* in *I. laurina*, a plant species that maintains viable populations of this fruit fly within its natural habitat. Because 70 percent of herbivore species exhibit a high level of specialization (Bernays and Chapman, 1994), knowledge of wild plant species that serve as hosts for fruit flies is relevant.

These results highlight the importance of increasing our knowledge about fruit fly/host plant interactions in natural environments.

Conclusions

Our findings shed light into host plant association for species of fruit flies and their parasitoids in natural environments and highlight the importance of tropical rainforests for the conservation of biodiversity. The areas of the Cerrado and Caatinga in Bom Jesus, that still preserve a great part of its original composition and structure exhibit a higher richness of wild fruits, such as those collected in this study. Consequently, represents a highly important reservoir for the diversity of fruit fly and native parasitoids spatially and temporally.

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Conflict of interest

The authors declare no conflicts of interest.

Author contribution statement

Edineia da Silva Araújo conducted the entire study, analyzed and interpreted the data and wrote the manuscript. Ricardo Fialho de Jesus and Thayline Rodrigues de Oliveira participated in the field stages and tabulation of data in the laboratory, analysis, and interpretation of the data. Luciana Barboza Silva participated in all stages from the conception and design of the study, as well as the analysis, review, and interpretation of the data. José Wellington Batista Lopes, interpretation of the data and review of the study and Gleidyane Novais Lopes contributed to the discussion and critical reading of the text.

References

Aluja, M., 1999. Fruit fly (Diptera: Tephritidae) research in Latin America: myths, realities, and dreams. An. Soc. Entomol. Bras. 28 (4), 565-594. http://dx.doi.org/10.1590/S0301-80591999000400001.

Aluja, M., Van Driesche, J., Driesche, R. V., Anzures-dadda, A., Guillén, L., 2014. Pest management through tropical tree conservation. Biodivers. Conserv. 23 (4), 831-853. http://dx.doi.org/10.1007/s10531-014-0636-3.

Alvarenga, C. D., Alves, D. A., Silva, M. A., Lopes, E. M., Lopes, G. N., 2009. Moscas-das-frutas (Diptera: Tephritidae) em pomares da área urbana no norte de Minas Gerais. Rev. Caatinga 23, 25-31.

Angiosperm Phylogeny Group IV – APG IV, 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Bot. J. Linn. Soc. 181 (1), 1-20. http://dx.doi.org/10.1111/boj.12385.

Araújo, A. A. R., Silva, P. R. R., Querino, R. B., Sousa, E. P. S., Soares, L. L., 2014. Moscas-das-frutas (Diptera: Tephritidae) associadas às frutíferas nativas de *Spondias* spp. (Anacardiaceae) e *Ximenia americana L.* (Olacaceae) e seus parasitoides no estado do Piauí, Brasil. Semina: Ciênc. Agrár. 35 (4), 1739-1750. http://dx.doi.org/10.5433/1679-0359.2014v35n4p1739.

Araujo, E. L., Fernandes, E. C., Silva, R. I. R., Ferreira, A. D. C. L., Costa, V. A., 2015. Parasitoides (Hymenoptera) de moscas-das-frutas (Diptera: Tephritidae) no semiárido do estado do Ceará, Brasil. Rev. Bras. Frutic. 37 (3), 610-616. http://dx.doi.org/10.1590/0100-2945-188/14.

Araujo, E. L., Medeiros, M. K. M., Silva, V. E., Zucchi, R. A., 2005. Moscas-das-frutas (Diptera: Tephritidae) no semiárido do Rio Grande do Norte: plantas hospedeiras e índices de infestação. Neotrop. Entomol. 34 (6), 889-894. http://dx.doi.org/10.1590/S1519-566X2005000600003.

Arbab, A., Mirphakhar, F., 2016. Spatial distribution pattern and sequential sampling plans for *Bactrocera oleae* (Gmelin) (Dip: Tephritidae) in olive orchards. J. Entomol. Acarol. Res. 48 (1), 23-28. http://dx.doi.org/10.4081/jear.2016.5533.

Barroso, G. M. 1984. Sistemática de angiospermas do Brasil. Vol. II. UFV, Viçosa.

Beitia, F., Valencia, E., Peris, B., Pedro, L., Asís, J. D., Tormos, J., 2016. Influence of natal host on parasitism by *Spalangia cameroni* (Hymenoptera: pteromalidae). Eur. J. Entomol. 113, 99-103. http://dx.doi.org/10.14411/eje.2016.012.

Bernays, E. A., Chapman, R. F., 1994. Behavior: the process of host-plant selection. In: Bernays, E.A., Chapman, R.F. (Eds.), Host-Plant Selection by Phytophagous Insects. Chapman & Hall, New York, pp. 95-165.

Bittencourt, M. A. L., Santos, O. O., Brito, E. A., Araujo, E. L., Marinho, C. F., 2012. Parasitoides (Braconidae) associados à *Anastrepha* (Tephritidae) em frutos hospedeiros do Litoral Sul da Bahia. Cienc. Agron. 43 (4), 811-815. http://dx.doi.org/10.1590/S1806-66902012000400024.

Borges, P. R. S., 2012. Characterization of black-winged peccary (*Mouriri pusa Gardner*) throughout its development. Federal University of Lavras, Lavras.

Cancino, J., Ruiz, L., Sivinski, J., Galvez, F. O., Aluja, M., 2009. Rearing of hymenopterous larval prepupal (Braconidae, Figitidae) and three pupal (Diapriidae, Chalcidoidea, Eurytomidae) native parasitoids of the genus *Anastrepha* (Diptera: Tephritidae) on irradiated *A. ludens* larvae and pupae. Biocontrol Sci. Technol. 19 (Suppl. 1), 193-209. http://dx.doi.org/10.1080/09583150802377423.

Coelho, J. B., Araújo, E. D. S., Silva, L. B., Strikis, P. C., Zucchi, R. A., Lopes, G. N., 2020. Frugivorous flies and their parasitoids associated with native fruits in an urban area. Semin. Ciên. Agrar. 41, 1053-1060. https://doi.org/10.5433/1679-0359.2020v41n3p1053.

Coelho, J. B., Araújo, E. D. S., Silva, L. B., Strikis, P., Lopes, G. N., 2018. Record of Neosilba zadolicha McAlpine & Steyskal (Diptera: Lonchaeidae) in mandacaru fruits. Arq. Inst. Biol. 85 (0), 1-3. http://dx.doi.org/10.1590/1808-1657000882016.

Costa, S. G. M. A., Querino, R. B. B., Ronchi-Teles, B. A., Penteado-Dias, A. M. M. C., Zucchi, R. A., 2009. Parasitoid diversity (Hymenoptera: Braconidae and Figitidae) on frugivorous larvae (Diptera: Tephritidae and Lonchaeidae) at Adolpho Ducke Forest Reserve, Central Amazon Region, Manaus, Brazil. Braz. J. Biol. 69 (2), 363-370. http://dx.doi.org/10.1590/S1519-69842009000200018.

Costa-Coutinho, J. M., Jardim, M. A. G., Castro, A. A. J. F., Viana-Junior, A. B., 2019. Conexões biogeográficas de savanas brasileiras: partição da diversidade marginal e disjunta e conservação do trópico ecotonal setentrional em um hotspot de biodiversidade. Rev. Bras. Geogr. Fis. 12 (7), 2406-2427. https://doi.org/10.26848/rbgf.v12.7.p2407-2427.

Deus, E. G., Adaime, R., 2013. Dez anos de pesquisas sobre moscas-das-frutas (Diptera: Tephritidae) no estado do Amapá: avanços obtidos e desafios futuros. Biota Amazôn. 3 (3), 157-168. http://dx.doi.org/10.18561/2179-5746/biotaamazonia.v3n3p157-168.

Deus, E. G., Pinheiro, L. S., Lima, C. R., Sousa, M. D. S. M., Guimarães, J. A., Strikis, P. C., Adaime, R., 2013. Wild hosts of frugivorous dipterans (Tephritidae and Lonchaeidae) and associated parasitoids in the Brazilian Amazon. Fla. Entomol. 96 (4), 1621-1625. http://dx.doi.org/10.1653/024.096.0453.

Enkerlin, W., Gutiérrez-Ruelas, J. M., Cortes, A. V., Roldan, E. C., Midgarden, D., Lira, E., López, J. L. Z., Hendrichs, J., Liedo, P., Arriaga, F. J. T., 2015. Area freedom in Mexico from Mediterranean fruit fly (Diptera: Tephritidae): a review of Over 30 years of a successful containment program using an integrated area-wide SIT approach. Fla. Entomol. 98 (2), 665-681. http://dx.doi.org/10.1653/024.098.0242.

Esri Inc. (2020). ArcGIS Pro (Version 2.5). Available in: https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview (accessed 5 May 2019).

Feitosa, S. S., Silva, P. R. R., Pádua, L. E. M., Sousa, M. P. S., Passos, E. P., Soares, A. A. R. A., 2007. Primeiro registro de moscas-das-frutas (Diptera: Tephritidae) em carambola nos municípios de Teresina, Altos e Parnaíba no oeste do Piauí. Semin. Ciên. Agrar. 28 (4), 629-634. http://dx.doi.org/10.5433/1679-0359.2007v28n4p629.

Feng, X., Murray, A. T., 2018. Allocation using a heterogeneous space Voronoi diagram. J. Geogr. Syst. 20 (3), 207-226. http://dx.doi.org/10.1007/s10109-018-0274-5.

Garcia, A. G., Araujo, M. R., Uramoto, K., Walder, J. M. M., Zucchi, R. A., 2017. Geostatistics and geographic Information system to analyze the spatial distribution of the diversity of *Anastrepha* Species (Diptera: Tephritidae): the effect of forest fragments in an urban area. Environ. Entomol. 46 (6), 1189-1194. http://dx.doi.org/10.1093/ee/nvx145.

Gibson, G. A. P., 2009. Revision of new world Spalangiinae (Hymenoptera: pteromalidae). Zootaxa 2259 (1), 1-159. http://dx.doi.org/10.11646/zootaxa.2259.1.1.

Instituto Nacional de Meteorologia – INMET, 2019. Available in: https://portal.inmet.gov.br/ (accessed 20 April 2019).

Institutos Nacionais de Ciência e Tecnologia – INCT, 2019. Herbário virtual da flora e dos fungos. Available in: http://inct.florabrasil.net (accessed 5 May 2019).

Joly, A. B., 1975. Botany: Identification Keys of Vascular Plant Families that Occur in Brazil. National Publishing Company Company, São Paulo.

Judd, W. S., Campbell, C. S., Kellog, E. A., Stevens, P. F., Donoghue, M. J., 2009. Sistemática vegetal: um enfoque filogenético, 3ª ed. Artmed, Porto Alegre, 632 pp.

Leal, M. R., Souza, S. A. S., Aguiar Menezes, E. L., Lima Filho, M., Menezes, E. B., 2009. Diversidade de moscas-das-frutas, suas plantas hospedeiras e seus parasitóides nas regiões Norte e Noroeste do Estado do Rio de Janeiro, Brasil. Cienc. Rural 39 (3), 627-634. http://dx.doi.org/10.1590/S0103-84782009005000002.

Lopes, G. N., Souza Filho, M. F., Gotelli, N. J., Lemos, L. U., Godoy, W. A. C., Zucchi, R. A., 2015. Temporal overlap and co-occurrence in a guild of subtropical tephritid fruit flies. PLoS One 10 (7), e0132124. http://dx.doi.org/10.1371/journal.pone.0132124.

López-Ortega, M., Díaz-Fleischer, F., Piñero, J. C., Valdez-Lazalde, J. R., Hernández-Ortiz, M., Hernández-Ortiz, V., 2020. The Mayan Tropical Rainforest: an uncharted Reservoir of Tritrophic host-fruit fly parasitoid interactions. Insects 11 (8), 495. http://dx.doi.org/10.3390/insects11080495.

Luz, C. L. S., Mitchell, J. D., Mitchell, J. D., Mitchell, J. D., Mitchell, J. D., Mitchell, J. D., Pirani, J. R., Pell, S. K., 2020. Anacardiaceae. In: Jardim Botânico do Rio de Janeiro (Ed.), Flora do Brasil 2020 em construção. JBRJ, Rio de Janeiro. Available in: http://reflora.jbrj.gov.br/reflora/floradobrasil/FB4380 (accessed 5 May 2019).

Macedo, W. S., Silva, L. S., Alves, A. R., Martins, A. R., 2019. Análise do componente arbóreo em uma área de ecótono Cerrado-Caatinga no sul do Piauí, Brasil. Sci. Plen. 15 (1), 010201. http://dx.doi.org/10.14808/sci.plena.2019.010201.

Midgarden, D., Lira, E., Silver, M., 2014. Spatial analysis of tephritid fruit fly traps. In: Shelly, T., Epsky, N., Jang, E.B., Reyes-Flores, J., Vargas, R.I. (Eds.), Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies: Lures, Area-Wide Programs, and Trade Implications. Springer, Dordrecht, pp. 277-320.

Mori, A. S., Silva, L. A. M., Lisboa, G., 1989. Manual de manejo do herbário fanerogâmico. Centro de Pesquisa do Cacau, Ilhéus, 104 pp.

Nicácio, J. N., Uchoa, M. A., Faccenda, O., Guimarães, J. Á., Marinho, C. F., 2011. Native larval parasitoids (Hymenoptera) of frugivorous Tephritoidea (Diptera) in South Pantanal region, Brazil. Fla. Entomol. 94 (3), 407-419. http://dx.doi.org/10.1653/024.094.0305.

Nicácio, J., Oliveira, I., Uchoa, M. A., Faccenda, O., Abot, A. R., Fernandes, M. G., Garcia, F. R. M., 2019. Spatial distribution and control levels of *Anastrepha* spp. (Diptera: Tephritidae) in guava orchards. An. Acad. Bras. Cienc. 91 (3), e20180428. http://dx.doi.org/10.1590/0001-3765201920180428.

Ovruski, S. M., Schliserman, P., Aluja, M., 2004. Indigenous parasitoids (Hymenoptera) attacking *Anastrepha aterculus* and *Ceratitis capitata* (Diptera: Tephritidae) in native and exotic host plants in Northwestern Argentina. Biol. Control 29 (1), 43-57. http://dx.doi.org/10.1016/S1049-9644(03)00127-0.

Ovruski, S., Aluja, M., Sivinski, J., Wharton, R., 2000. Hymenopteran parasitoids on fruit-infesting Tephritidae (Diptera) in Latin America and the southern United States: diversity, distribution, taxonomic status and their use in fruit fly biological control. Integr. Pest Manage. Rev. 5 (2), 81-107. http://dx.doi.org/10.1023/A:1009652431251.

Paula Filho, F. J., Moura, M. C. S., Marins, R. V., 2012. Fracionamento geoquímico do fósforo em água e sedimentos do Rio Corrente, bacia hidrográfica do Parnaíba/PI. Rev. Virt. Quim. 4, 623-640. https://doi.org/10.5935/1984-6835.20120048.

Pirovani, V. D., Martins, D. S., Souza, S. A. S. K., Uramoto, K., Ferreira, P. S. F., 2010. Moscas-das-frutas (Diptera: Tephritidae), seus parasitóides e hospedeiros em Viçosa, zona-da-mata mineira. Arq. Inst. Biol. 77 (4), 727-733. http://dx.doi.org/10.1590/1808-1657v77p7272010.

Sá, R. F., Castellani, M. A., Nascimento, A. S., Ribeiro, A. E. L., Moreira, A. A., 2012. Parasitismo natural em moscas-das-frutas (Diptera: Tephritidae) no semiárido do Sudoeste da Bahia, Brasil. Rev. Bras. Frutic. 34 (4), 1266-1269. http://dx.doi.org/10.1590/S0100-29452012000400036.

Santos, T. C., Nascimento Júnior, J. E., Prata, A. P. N., 2012. Frutos da Caatinga de Sergipe utilizados na alimentação humana. Sci. Plena. 8, 1-8. Available in: https://www.scientiaplena.org.br/sp/article/view/698 (accessed 18 February 2020).

Schliserman, P., Aluja, M., Rull, J., Ovruski, S. M., 2016. Temporal diversity and abundance patterns of parasitoids of fruit-infesting Tephritidae (Diptera) in the Argentinean Yungas: implications for biological control. Environ. Entomol. 45 (5), 1184-1198. http://dx.doi.org/10.1093/ee/nvw077.

Sciarretta, A., Tabilio, M. R., Lampazzi, E., Ceccaroli, C., Colacci, M., Trematerra, P., 2018. Analysis of the Mediterranean fruit fly [*Ceratitis capitata* (Wiedemann)] spatiotemporal distribution in relation to sex and female mating status for precision IPM. PLoS One 13 (4), e0195097. http://dx.doi.org/10.1371/journal.pone.0195097.

Silva, B., Silva, H., Fernandes, E., Costa, V., Araújo, E., 2020. Pupal parasitoids associated with *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) in a semiarid environment in Brazil. Rev. Bras. Entomol. 64, 2. https://doi.org/10.1590/1806-9665-RBENT-2019-0002.

Silva, J. G., Dutra, V. S., Santos, M. S., Silva, N. M., Vidal, D. B., Nink, R. A., Guimaraes, J. A., Araujo, E. L., 2010. Diversity of *Anastrepha* spp. (Diptera: Tephritidae) and associated braconid parasitoids from native and exotic hosts in Southeastern Bahia. Brazil. Environ. Entomol. 39 (5), 1457-1465. http://dx.doi.org/10.1603/EN10079.

Soberón, J. M., 2010. Niche and area of distribution modeling: a population ecology perspective. Ecography 33 (1), 159-167. http://dx.doi.org/10.1111/j.1600-0587.2009.06074.x.

Sousa, M. M., Fernandes, D. C., Ferreira, E. C. A., Araujo, E. L., 2017. Moscas-das-frutas (Diptera: Tephritidae) e seus hospedeiros no município de Quixeré, estado do Ceará, Brasil. Rev. Verde. 12, 530-534. https://doi.org/10.18378/rvads.v12i3.5371.

Sousa, M. S. M., Barros, R. J., Yokomizo, G. K., Lima, A. L., Adaime, R., 2016. Ocorrência de moscas-das-frutas e parasitoides em *Spondias mombin* L. em três municípios do estado do Amapá, Brasil. Biota Amazôn. 6 (2), 50-55. http://dx.doi.org/10.18561/2179-5746/biotaamazonia.v6n2p50-55.

Souza, E. G., Acioli, A. N. S., Silva, N. M., Costa-Silva, F. C., 2018. New host records for species of *Anastrepha* (Diptera: Tephritidae) in the state of Amazonas, Brazil. Arq. Inst. Biol. 85 (0), 1-3. http://dx.doi.org/10.1590/1808-1657000842017.

Souza, F. X., Costa, J. T. A., Lima, R. N., 2006. Características morfológicas e fenológicas de clones de cajazeira cultivados na Chapada do Apodi, Ceará. Cienc. Agron. 37, 208-215. https://doi.org/10.1590/S1806-66902012000200012.

Souza, M. P., Coutinho, J. M. C. P., Silva, L. S., Amorim, F. S., Alves, A. R., 2017. Composição e estrutura da vegetação de Caatinga no sul do Piauí, Brasil. Rev. Verde 12 (2), 210-217. http://dx.doi.org/10.18378/rvads.v12i2.4588.

Sugayama, R. L., Malavasi, A., 2000. Ecologia comportamental. In: Malavasi, A., Zucchi, R.A. (Eds.), Moscas-das-frutas de importância económica no Brasil: conhecimento básico e aplicado. Holos, Ribeirão Preto, pp. 103-108.

Teixeira, C. M., Krüger, A. P., Nava, D. E., Garcia, F. R., 2021. Potential global distribution of the south American cucurbit fruit fly *Anastrepha grandis* (Diptera: tephritidae). J. Crop. Prot. 145, 105647. http://dx.doi.org/10.1016/j.cropro.2021.105647.

The Brazil Flora Group. 2018. Brazilian Flora 2020: Innovation and collaboration to meet Target 1 of the Global Strategy for Plant Conservation (GSPC). Rodriguésia. 69 (4), 1513-1527. https://doi.org/10.1590/2175-7860201869402.

Uchôa-Fernandes, M. A., Molina, R. M. S., Oliveira, I., Zucchi, R. A., Canal, N. A., Díaz, N. B., 2003. Larval endoparasitoids (Hymenoptera) of frugivorous flies (Diptera, Tephritoidea) reared from fruits of te Cerrado of the State of Mato Grosso do Sul, Brazil. Rev. Bras. Entomol. 47 (2), 181-186. http://dx.doi.org/10.1590/S0085-56262003000200005.

Uchôa-Fernandes, M. A., Oliveira, I. D., Molina, R. M. S., Zucchi, R. A., 2002. Species diversity of frugivorous flies (Diptera: Tephritoidea) from hosts in the Cerrado of the state of Mato Grosso do Sul, Brazil. Neotrop. Entomol. 31 (4), 515-524. http://dx.doi.org/10.1590/S1519-566X2002000400002.

Uramoto, K., Martins, D. S., Zucchi, R. A., 2008. Fruit flies (Diptera, Tephritidae) and their associations with native host plants in a remnant area of the highly endangered Atlantic Rainforest in the State of Espírito Santo, Brazil. Bull. Entomol. Res. 98 (5), 457-466. http://dx.doi.org/10.1017/S0007485308005774.

Vieira, F. N. D. S., Sousa, E. M. D., Louzeiro, L. R. F., Silva, S. B., 2019. Lonchaeidae (Diptera) species and their host plants in the Cerrado biome in the state of Piauí, Brazil. Arq. Inst. Bio. 86, e0242018. http://dx.doi.org/10.1590/1808-1657000242018.

Zucchi, R. A., 2000. Espécies de *Anastrepha*, sinonímias, plantas hospedeiras e parasitoides. In: Malavasi, A., Zucchi, R.A. (Eds.), Moscas-das-frutas de importância económica no Brasil: conhecimento básico e aplicado. Holos, Ribeirão Preto, pp. 41-48.

Zucchi, R. A., Moraes, R. C. B., 2012. Moscas da fruta no Brasil - hospedeiros e parasitoides da mosca da fruta do Mediterrâneo. Available in: www.lea.esalq.usp.br/Ceratitis/ (accessed 18 February 2020).

Zucchi, R. A., Moraes, R. C. B., 2022. Fruit flies in Brazil - *Anastrepha* species their host plants and parasitoids. Available in: http://www.lea.esalq.usp.br/anastrepha (accessed 5 May 2019).