Diversity of Fruit Flies (Diptera: Tephritoidea) and Their Host Plants in a Conservation Unit from Midwestern Brazil

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Diversity of fruit flies (Diptera: Tephritoidea) and their host plants in a conservation unit from midwestern Brazil

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Abstract

Fruit flies (Diptera: Tephritoidea and Lonchaeidae) are among the principal phytophagous insects of fruit and vegetables. Their larvae feed on the pulp or seeds of fruits to complete their development, which favors the entry of pathogens and early fall of the fruits, damaging fruit production. The objectives of this research were to determine the richness of fruit fly species and their associations with their host fruits in the Serra da Bodoquena National Park (Mato Grosso do Sul State, Brazil) and surrounding areas. To obtain the fruit fly species from their hosts, monthly collections of fruits were made. Leaf samples were prepared and identified by botanists. The collected fruits were transported to the Laboratório de Insetos Frugívoros, where they were counted and weighed. The species of fruit flies were identified, and their trophic interactions with their hosts analyzed. Thirty-nine plant species from 29 plant families were collected. Twelve fruit species were hosts to fruit fly larvae. The survey resulted in the recovery of 1,476 larvae and 968 adult fruit flies. Among the adults, 878 were Tephritidae and 90 Lonchaidae. Nine species from the genus Anastrepha (Diptera: Tephritoidea) and 3 from Neosilba (Diptera: Lonchaeidae) were obtained. These are the first reports for Anastrepha serpentina (Wiedemann), Anastrepha fraterculus (Wiedemann), and Anastrepha obliqua (Macquart) (all Diptera: Tephritoidea) infesting fruits of Eugenia myrcianthes Nied (Myrtaceae); Anastrepha striata Schiner (Diptera: Tephritoidea) infesting Jacaratia spinosa Aubl. (Caricaceae); Anastrepha vespidae Zucchi (Diptera: Tephritoidea) infesting Campomanesia guazumifolia (Cambess) O. Berg. (Myrtaceae); Neosilba glaberrima (Wiedemann) and Neosilba zadolicha McAlpine & Steyskal are recorded for the first time infesting Persea americana Miller (Lauracea), and Neosilba certa (Walker) (all Diptera: Lonchaeidae) infesting Chrysophyllum gonocarpum (Mart. & Eichler) Engl. (Sapotaceae), Anastrepha barbiellinii Lima (Diptera: Tephritoidea) is recorded for the first time infesting Pereskia aculeata Miller (Cactaceae) in Mato Grosso do Sul State.

Key Words: Anastrepha spp.; host fruits; trophic interactions; Neosilba spp.; infestation

Resumo

As moscas das frutas (Diptera: Tephritoidea e Lonchaeidae), estão entre os principais insetos fitófagos em frutíferas e hortícolas. Suas larvas, ao se alimentarem da polpa ou das sementes dos frutos para completar o desenvolvimento, podem favorecer a entrada de patógenos ou quebra precoce dos frutos, prejudicando a produção. Os objetivos desta pesquisa foram conhecer a riqueza em espécies de moscas das frutas e suas associações com seus frutos hospedeiros no Parque Nacional da Serra da Bodoquena (Mato Grosso do Sul, Brasil) e arredores. Para a obtenção das moscas das frutas a partir dos seus hospedeiros foram realizadas expedições mensais para amostragem de frutos. Foram preparadas exsicatas das frutíferas amostradas, que foram identificadas por botânicos. Os frutos coletados foram transportados ao Laboratório de Insetos Frugívoros, onde foram contados e pesados. As espécies de moscas das frutas foram identificadas e suas interações tróficas com seus hospedeiros analisadas. Foram coletadas 39 espécies frutíferas pertencentes a 29 famílias. Doze espécies frutíferas foram hospedeiras de larvas de moscas das frutas, sendo obtidas 1.476 larvas de moscas das frutas, com 968 adultos: 878 de Tephritoidea e 90 de Lonchaeidae. Nove espécies do gênero Anastrepha (Diptera: Tephritoidea) e 3 de Neosilba (Diptera: Lonchaeidae) foram obtidas. Estes são os primeiros relatos de: Anastrepha serpentina (Wiedemann), Anastrepha fraterculus (Wiedemann) e Anastrepha obliqua (Macquart) (todos Diptera: Tephritoidea) infestando frutos de Eugenia myricanthes Nied (Myrtaceae); Anastrepha striata Schiner (Diptera: Tephritoidea) em Jacaratia spinosa Aubl. (Caricaceae), Anastrepha z velocidae Zucchi (Diptera: Tephritoidea) em Campomanesia guazumifolia (Cambess) O. Berg. (Myrtaceae), Neosilba glaberrima (Wiedemann) e Neosilba zadolicha McAlpine & Steyskal são reportadas pela primeira vez infestando Persea americana Miller (Lauracea) e Neosilba certa (Walker) (todos Diptera: Lonchaeidae) infestando Chrysophyllum gonocarpum (Mart. & Eichler) Engl. (Sapotaceae), Anastrepha barbiellinii Lima (Diptera: Tephritoidea) é registrada pela primeira vez infestando Pereskia aculeata Miller (Cactaceae) em Mato Grosso do Sul.

Palavras Chave: Anastrepha spp.; frutos hospedeiros; interações tróficas; Neosilba spp.; infestação

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Almeida et al.: Biodiversity of fruit flies and their host plants

In Brazil, fruticulture is one of the most important elements of the agricultural economy. Of the 5.7 million ha devoted to agricultural crops, fruit trees occupy 27.3% (Vitti 2009). According to FAO (2019), in 2016 Brazil was the third largest fruit producer in the world, after China and India, with 42.3 million metric tons.

The fruit and fruit byproducts sector is considered the largest generator of jobs in Brazil, occupying 40% of the Brazilian agribusiness labor force. Farms with fruit and vegetable cultivations are characterized by being from small to medium-sized (10–50 ha). To each R $20,000 invested in horticulture, 3 to 5 jobs are generated along the production chain (Vitti 2009).

Despite being the third largest fruit producer in the world, Brazil occupies the twenty-third place in the ranking of exporting countries (Anuário Brasileiro de Fruticultura 2018). One of the principal problems faced by exporters of fruits and vegetables in the country is the occurrence of a great diversity of fruit fly species. Such species cause constant concern to importing countries, which often are free from these pests. These nations invest heavily in their agriculture, and impose severe quarantine restrictions on imports of fresh goods from countries where fruit fly pest species occur. In order to meet the sanitary requirements imposed by importing countries, producer nations are obliged to take several preventive measures, such as thermal treatment for some species of fruit, such as mango (*Mangifera indica* L.) (*Anacardiaceae*). They also require the demarcation of fruit fly-free areas or areas with low prevalence of fruit flies in order to get export permits (Uchoa 2012).

Fruit flies herein considered are frugivorous species from the families Tephritidae and Lonchaeidae (sensu Uchoa 2012). The most important tephritid genera are *Anastrepha* Schiner, *Bactrocera* Macquart, *Ceratitis* Macleay, *Dacus* Fabricius, and *Rhagoletis* Loew (Tephritidae). In the family Lonchaeidae, the most important genera are *Dasiops* Rondani and *Neosilba* McAlpine (Uchoa 2012).

Management of fruit flies is challenging because the eggs are inserted into the fruit, and the larvae that feed inside the fruit leave the fruit to pupate in the soil. Thus, they may escape contact with insecticides (Heve et al. 2016).

In the Neotropical region, more than 300 species of *Anastrepha* have been described (Norrbom et al. 1999, 2012, 2015) based on adult morphological studies. Recently, the genus *Toxotrypana* Gerstaecker was combined with *Anastrepha*, increasing the number of valid species in this taxon (Norrbom et al. 2018). These flies cause about US $120 to 200 million annual losses to Brazilian horticulture (Felix et al. 2009).

The family Lonchaeidae, with 587 species described worldwide, is subdivided into 2 subfamilies: Dasioptinae and Lonchaeinae. Dasioptinae has 128 described species in a single genus: *Dasiopt* Rondani, followed by Lonchaeinae, with 8 genera: *Protaromymia* McAlpine (12), *Chaetolonchaecia* McAlpine (Steyskall & Henning) (8), *Earomyia* Macquart (22), *Lamprolonchaecia* Czerni (17), *Fullgena* Mcagan (15), *Lonchaea* Fallen (232), *Silba* Rondani (113), and *Neosilba* Steyskall (40) (McGowan 2018).

Most research on tephritoids focuses on the economic importance of several species associated with agriculture (Lemos et al. 2015), whereas studies in native areas (Uramoto et al. 2008; Uchoa & Nicácio 2010) are scarce. Protected natural areas, such as conservation units, represent one of the best strategies to conserve local biodiversity. Such areas play an important role in the conservation of regional biodiversity, as well as in the ecological processes that occur in these environments. In the case of fruit flies, it is very important to conserve their alternative hosts, and the monophagous and stenophagous tephritoid species (Aluja & Mangan 2008), because juvenile and adult non-pest species can persist in preserved environments, and natural enemies can proliferate and be studied for use in programs of biological control of fruit fly pest species in orchards and vegetable gardens.

Knowledge about the biodiversity of fruit flies in conservation units allows us to obtain essential information for management techniques, besides providing additional data on fauna potentially affecting fruit crops (Bomfim et al. 2007). In this context, the purpose of this study was to determine the richness of fruit fly species and their associations with host plants in the Parque Nacional da Serra da Bodoquena and surrounding areas.

**Material and Methods**

**STUDY AREA**

The fruit collections were carried out in the Parque Nacional da Serra da Bodoquena (at 20.341000°S, 56.513900°W) and farms along the access road to the park, which integrate the buffer zone. This park is located in the Cerrado biome, but the proximity to other biomes and the distance from the Cerrado nuclear region suggest influences of the Pantanal and Atlantic forest. The total area of the park is 76,481 ha. It consists of 2 large geomorphological blocks with distinct characteristics: 1 to the north with an area of 27,793 ha, and the other to the south with 48,688 ha (PNSB 2013). The park consists mostly of submontane deciduous seasonal forest (about 70,000 ha), followed by areas of savannah (3,564 ha), floodplains (379 ha), and anthropized areas (2,576 ha) (PNSB 2013).

Fruit sampling was carried out on 3 trails that had been pre-established by the Instituto Chico Mendes de Conservação da Biodiversidade for the periodic monitoring of flora and fauna in the park. These trails start at the end of the buffer zone leading to the interior of the park. The trails are designated Marambáia, Santa Fé, and Catamarca.

**Marambáia Trail** (20.580700°S, 56.422300°W)

The predominant vegetation is shrubs and large trees (between 3 and 30 m in height), with characteristics of semideciduous submontane forest. This area is close to domestic orchards at the headquarters of the surrounding farms, and displays great species richness, including cultivated fruits, such as passion fruit (*Passiflora* spp.) (*Passifloraceae*), mango (*Mangifera indica* L.) (*Anacardiaceae*), red-mobim (*Spondias purpurea* L.) (*Anacardiaceae*), and avocado (*Persea americana*) (Miller) (*Lauraceae*), among others.

**Santa Fé Trail** (21.302600°S, 56.450500°W)

The Santa Fé trail is characterized by a mountainous region, with shallow soil and many rocky outcrops (soil surface with large blocks of rocks), making it difficult to establish large trees. This area is close to farms with annual grain crops, alternating soybean (spring to summer) and corn (late summer to winter) plantations.

**Catamarca Trail** (21.616000°S, 56.432800°W)

This area is characterized by open cerrado (arborreal savanna) and ciliary forest, with typical vegetation of semideciduous submontane tropical forest. The area along this trail displays human impact, with interspersed pastures in the cerrado vegetation, including farming activities (cattle breeding), intense deforestation, and artificial diversion of the Perdido River in some stretches, which interrupts the natural ecology.

**FRUIT SAMPLING FOR TEPHRITOIDEA**

Fruits were sampled monthly from Jan 2017 to Feb 2018. The fruit fly species were obtained from native wild fruits, or from naturally oc-
curing cultivated fruit such as avocado, guava L. (Myrtaceae), and cajá (Spondias mombin L.) (Anacardiaceae).

In order to inventory the fruit flies, fruits of different plant taxa were sampled along the trails (Marambaia, Santa Fé, and Catamarca). About 2,500 m of trail length were sampled for each trail, and the fruits were sampled at a distance of approximately 2.5 m from each side of the trail, totaling a sampled area of about 37,500 m² (12,500 m² on each trail). The collected fruits were taken directly from the trees and also from the ground if they were freshly fallen.

The leaf samples taken from the trees were identified by Zefa Valdivina Pereira, Faculdade de Ciências Biológicas e Ambientais, Universidade Federal da Grande Dourados, Dourados, Mato Grosso do Sul, Brazil, and Ângela Sartori, Departamento de Biologia, Universidade Federal de Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul, Brazil.

The collected fruits were placed in cotton bags and transported to the laboratory, where later they were transferred to wooden pallets inserted in trays containing a shallow layer of water (1 ± 1 cm) to collect the last instar larvae of fruit flies. Larvae were collected daily every 12 h from the trays, and inserted into transparent acrylic pots with sterilized sand, where they remained until adult emergence.

Identification of adult Tephritidae was performed by M. A. Uchoa based on body and wing color patterns of adults and examination of female genital morphology, using a stereomicroscope (Zeiss, Discovery V-8, Dourados, Mato Grosso do Sul State, Brazil) and taxonomic identification keys (Stone 1942; Steyskal 1977; Zucchi 2000). Identification of Anastrepha species is based principally on morphometric characteristics of females.

The Lonchaeidae were identified by L. J. Gistloti based on morphological examination of the genitalia of males using identification keys (Korytowsky & Ojeda 1971; McAlpine & Steyskal 1982; Galeano-Olaya et al. 2012). In Lonchaeidae, identification is based only on male genital characters.

DATA ANALYSIS

The analysis of the patterns of fruit fly infestation in their hosts was based on Uchoa et al. (2003). The parameters calculated were: (1) viability of third instar larvae (percentage of unparasitized larvae) was calculated as the number of emerged fruit flies per fruit × 100 divided by total number of third instar larvae in each fruit-number of non-emerged parasitoids; (2) richness was calculated as the total number of fruit fly species collected in each plant community. These communities were represented by each of the trails sampled: Marambaia, Santa Fé, and Catamarca; (3) the rates of fruit fly infestation were calculated according to Uchoa et al. (2003) using the following parameters: (3a) dividing the total number of third instar flies larvae (L3) by the number of fruits in the sample (L3 per fruit), and (3b) dividing the total number of third instar larvae by the total mass (g) of sample (L3 per g).

Results

A total of 7,389 fruits from 39 fruit species of 29 plant families were collected, totaling 32,242 g of fruits (Table 1). Twelve species of fruit from 8 plant families were hosts to fruit fly larvae: Spondias mombin (Anacardiaceae), Pereskia aculeata Miller (Cactaceae), Jacaranda spinosa (Aubl.) ADC (Caricaceae), Eugenia myrcianthes Nied. (Myrtaceae), Psidium guajava L. (Myrtaceae), Campomanesia guazumifolia (Cambess.) O. Berg (Myrtaceae), Psidium guineense (Swartz.) Myrtaceae, Passiflora alata Curtis (Passifloraceae), Passiflora gibertii N. E. Br. (Passifloraceae), Persea americana Mill. (Lauraceae), Randia ferox (Cham. & Schldl.) DC (Rubiacae), and Chrysophyllum gonocarpum (Mart. & Eichler) Engl. (Sapotaceae) (Table 1).

Among the 8 host plant families of fruit flies, 7 fruit species were infested by Tephritidae: cajá (S. mombin), ora pro nóbis (P. aculeata), guava (P. guajava), sweet passion fruit (P. alata), jaca-táriá (J. spinosa), sete-capotes (C. guazumifolia), araçá (P. guineense), and 3 by Lonchaeidae: avocado (P. americana), espinho cruz (R. ferox), and wild silver passion fruit (P. gibertii). Two species, ubajá (E. myrcianthes) and aguá (C. gonocarpum), were infested by both families of Tephritoidae (Table 1).

From the host fruits, 1,476 larvae of fruit flies were obtained, which produced 968 adults consisting of 878 tephritids and 90 lonchaeids (Table 1). Twelve species of fruit flies were recovered, including 9 species of Anastrepha (Tephritidae), and 3 of Neosilba ( Lonchaeidae): Anastrepha sororcula Zucchi, Anastrepha striata Schiner, Anastrepha pseudoparallela (Loew), Anastrepha barbiellinii Costa Lima, Anastrepha obliqua (Macquart), Anastrepha fraterculus (Wiedemann), Anastrepha serpentina (Wiedemann), Anastrepha elegans Blanchard, Anastrepha zenildae Zucchi (all Tephritidae), Neosilba certa Walker, Neosilba glaberrima (Wiedemann), and Neosilba zadolicha McAlpine & Steyskal (all Lonchaeidae) (Table 1).

Chrysophyllum gonocarpum was the host with the highest frugivorous tephritid species richness (6), and was infested by 246 adults: A. elegans (1 adult), A. fraterculus (2), and A. serpentina (234). The last 2 associations are new records between species of fruit flies and host fruit. The following Neosilba species (Lonchaeidae) also were recovered from this host: N. certa (1 adult), N. glaberrima (1), N. zadolicha (4), and Neosilba sp. (3).

Other hosts also were infested by multiple species of fruit flies. Eugenia myrcianthes was second in terms of species richness of fruit flies infesting their fruits: A. sororcula (9), A. serpentina (1), A. fraterculus (45), A. obliqua (4), and Neosilba sp. (6).

Camponanesia guazumifolia was infested by 4 species: A. fraterculus (4), A. zenildae (3), A. sororcula (4), and A. obliqua (1), followed by P. guineense with 3 frugivorous species: A. sororcula (151), A. fraterculus (25), and A. zenildae (1). Psidium guajava was infested by 3 species: A. sororcula (71), A. striata (3), and A. fraterculus (1); S. mombin by A. striata (1), and A. obliqua (2); P. alata by A. pseudoparallela (10); P. gibertii by Neosilba spp. (6♀♀); P. aculeata by A. barbiellinii (28); J. spinosa by A. striata (1); R. ferox was infested by 3 ♀♀ of Neosilba spp.; and P. americana was infested by 2 species of Lonchaeidae: N. glaberrima (30) and N. zadolicha (8) (Table 1).

ABUNDANCE

Anastrepha sororcula was the most abundant species (n = 235), followed by A. serpentina (n = 234), A. fraterculus (n = 45), A. barbiellinii (n = 28), A. pseudoparallela (n = 10), A. striata (n = 5), A. obliqua (n = 4), and A. elegans (n = 1).

The most abundant species of Lonchaeidae were Neosilba zadolicha (n = 30), N. glaberrima (n = 8), and Neosilba sp. (1) (Table 1).

SPECIES RICHNESS

The highest species richness of tephritids (n = 8) was recorded along the Marambaia Trail (Bonito, Mato Grosso do Sul, Brazil), where the following species were recovered: A. striata and A. obliqua from S. mombin; A. barbiellinii from P. aculeata; A. zenildae from P. guineense and C. guazumifolia; A. sororcula and A. fraterculus from P. guineense; and A. striata from J. spinosa. Neosilba glaberrima, N. zadolicha, and Neosilba sp. were obtained from P. americana; A. fraterculus, A. obli-
Table 1. Fruit flies emerging from fruit sampled from host or non-host plants collected at Parque Nacional da Serra da Bodoquena and surrounding areas (Bonito and Jardim, Mato Grosso do Sul), Brazil, from Jan 2017 to Feb 2018.

| Plant family | Plant species               | Fruit (g) | Fruits (n) | Larvae (n) | Adults (n) | Fruit fly species (n) |
|--------------|-----------------------------|-----------|------------|------------|------------|----------------------|
| Anacardiaceae| *Spondias mombin*           | 1,047     | 67         | 3          | 3          | *Anastrepha obliqua* (2) |
|              |                             |           |            |            |            | *Anastrepha striata* (1) |
| Annonaceae   | *Unonopsis guatterioides*   | 90        | 185        | 0          | 0          |                      |
| Araceae      | *Anthurium sp.*             | 163       | 432        | 0          | 0          |                      |
| Arecales     | *Allagoptera caudescens*    | 1,695     | 683        | 0          | 0          |                      |
|              | *Attalea speciosa*          | 506       | 321        | 0          | 0          |                      |
| Boraginaceae | *Cordia sellowiana*         | 214       | 228        | 0          | 0          |                      |
| Bromeliaceae | *Ananas ananassoides*       | 2,949     | 26         | 0          | 0          |                      |
| Bignoniaceae | *Fridericia floridana*      | 20        | 5          | 0          | 0          |                      |
| Cactaceae    | *Opuntia stricta*           | 40        | 5          | 0          | 0          | *Anastrepha barbiellini* |
|              | *Pereskia aculeata*         | 300       | 112        | 51         | 28         | Neosilba sp. |
| Caricaceae   | *Jacaratia spinosa*         | 1,632     | 31         | 2          | 2          | *Anastrepha striata* (1) |
|              |                             |           |            |            |            | *Anastrepha sp.* (1) |
| Combretaceae | *Terminalia triflora*       | 18        | 27         | 0          | 0          |                      |
| Curculitaceae| *Melothria pendula*         | 97        | 140        | 0          | 0          |                      |
| Euphorbiaceae| *Sebastiania sp.*          | 80        | 183        | 0          | 0          |                      |
| Lauraceae    | *Persea americana*          | 7,823     | 8          | 110        | 75         | Neosilba zadolicha (30) |
|              |                             |           |            |            |            | Neosilba globerrima (8) |
|              |                             |           |            |            |            | Neosilba spp. (33) |
| Lecythidaceae| *Cariniana sp.*             | 647       | 51         | 0          | 0          |                      |
| Fabaceae     | *Peltophorum dubium*        | 192       | 255        | 1          | 0          |                      |
| Myrtaceae    | *Psidium guajava*           | 1,038     | 65         | 191        | 80         | *Anastrepha sororcula* (71) |
|              |                             |           |            |            |            | *Anastrepha striata* (3) |
|              |                             |           |            |            |            | *Anastrepha fraterculus* (1) |
|              |                             |           |            |            |            | *Anastrepha spp.* (5) |
|              | *Campomanesia guazumifolia* | 489       | 74         | 30         | 19         | *Anastrepha fraterculus* (4) |
|              |                             |           |            |            |            | *Anastrepha zenilae* (3) |
|              |                             |           |            |            |            | *Anastrepha sororcula* (4) |
|              |                             |           |            |            |            | *Anastrepha obliqua* (1) |
|              |                             |           |            |            |            | *Anastrepha sp.* (7) |
|              | *Psidium guineense*         | 1,047     | 75         | 576        | 356        | *Anastrepha sororcula* (151) |
|              |                             |           |            |            |            | *Anastrepha fraterculus* (25) |
|              |                             |           |            |            |            | *Anastrepha zenilae* (1) |
|              |                             |           |            |            |            | *Anastrepha spp.* (179) |
|              | *Eugenia myrcianthes*       | 779       | 133        | 197        | 145        | *Anastrepha fraterculus* (45) |
|              |                             |           |            |            |            | *Anastrepha sororcula* (9) |
|              |                             |           |            |            |            | *Anastrepha obliqua* (4) |
|              |                             |           |            |            |            | *Anastrepha serpentina* (1) |
|              |                             |           |            |            |            | *Anastrepha spp.* (85) |
|              |                             |           |            |            |            | Neosilba sp. (6) |
| Myrsinaceae  | *Myrsine guianensis*        | 12        | 60         | 0          | 0          |                      |
| Myctoginaceae| *Guapira opposita*          | 1,061     | 403        | 0          | 0          |                      |
| Moraceae     | *Maclura tinctoria*         | 141       | 89         | 0          | 0          |                      |
| Passifloraceae| *Passiflora alata*         | 1,649     | 10         | 30         | 10         | *Anastrepha pseudoparallela* |
|              | *Passiflora giberti*        | 257       | 17         | 5          | 5          | Neosilba sp. |
| Phyllantaceae | *Margarita nobilis*        | 489       | 118        | 0          | 0          |                      |
| Primulaceae  | *Clavija sp.*               | 45        | 20         | 0          | 0          |                      |
| Rhaminaceae  | *Rhamnuidium elaeocarpum*   | 464       | 598        | 0          | 0          |                      |
A. sororcula, A. serpentina, and Neosilba sp. from E. myrcianthes; and A. serpentina from C. gonocarpum.

Along the Santa Fé trail (Jardim, Mato Grosso do Sul, Brazil), only 3 species were recovered: A. sororcula and A. striata from P. guajava; and A. barbiellinii from P. aculeata (Table 2).

Along the Catamarca trail (Bonito, Mato Grosso do Sul, Brazil), a single species was obtained: A. serpentina, in the fruits of E. myrcianthes (Table 2).

The highest rates of fruit fly infestation occurred in fruit samples from the Marambaia and Santa Fé trails. In some cases only 1 species of tephritid or lonchaeid per host was recovered (Table 2).

### VIABILITY AND INFESTATION INDICES

The viability indices (% flies not infested by parasitoids) per fruit fly species were R. ferox with 100% viability, P. gibertii (100%), J. spinosa (100%), and A. serpentina (88.1%).

| Host fruits (family, species) | Location          | Third instar larvae (n) | Adults (n) | Viability (% unparasitized) |
|-----------------------------|-------------------|-------------------------|-----------|-----------------------------|
| Anacardiaceae               | Marambaia Trail   | 3                       | 2         | 66.6                        |
| Spondias mombin             | Tephritidae       |                         |           |                             |
| Cactaceae                   | Santa Fé Trail    | 51                      | 28        | 55                          |
| Pereskia aculeata           | Tephritidae       |                         |           |                             |
| Caricaceae                  | Marambaia Trail   | 1                       | 1         | 100                         |
| Jacaranda spinosa           | Lonchaeidae       |                         |           |                             |
| Lauraceae                   | Marambaia Trail   | 110                     | 75        | 68                          |
| Myrtaceae                   | Tephritidae       |                         |           |                             |
| Eugenia myrcianthes         | Marambaia Trail   | 197                     | 145       | 73.6                        |
| Psidium guajava             | Santa Fé Trail    | 191                     | 80        | 42                          |
| Psidium guineense           | Marambaia Trail   | 576                     | 356       | 61.8                        |
| Campomanesia guazumifolia   | Lonchaeidae       |                         |           |                             |
|                            | Marambaia Trail   | 30                      | 19        | 63.3                        |
|                            |                    |                         |           |                             |
| Passifloraceae              | Marambaia Trail   | 30                      | 10        | 33.3                        |
| Passiflora alata            | Tephritidae       |                         |           |                             |
| Passiflora gibraltar        | Marambaia Trail   | 5                       | 5         | 100                         |
| Rubiaceae                   | Lonchaeidae       |                         |           |                             |
| Randia ferox                | Catamarca Trail   | 3                       | 3         | 100                         |
| Sapotaceae                  | Tephritidae       |                         |           |                             |
| Chrysophyllum gonocarpum    | Marambaia Trail   | 279                     | 246       | 88.1                        |

### Table 2. Viability indices (unparasitized) of fruit flies (Diptera: Tephritidae and Lonchaeidae) and their association with host fruits in the interior of Parque Nacional da Serra da Bodoquena and surrounding areas (Bonito and Jardim, Mato Grosso do Sul), Brazil, from Jan 2017 to Feb 2018.
(100%), followed by C. gonocarpum (88.1%), E. myrcianthes (73.6%), P. americana (68%), S. mombin (66.6%), C. guazumifolia (63.3%), P. guineense (61.8%), P. aculeata (55%), and P. alata (33.3%). The viability index of Tephritidae was 90.7% and for Lonchaeidae it was 9.3% (Table 2).

The fruit trees with the highest fruit infestation rates (number of larvae per fruit) were P. americana (13.75), P. guineense (7.6), P. alata (3), P. guava (2.9), C. guazumifolia (2.4), E. myrcianthes (1.48), C. gonocarpum (1.18), P. aculeata (0.45), P. giberi (0.29), P. alata (0.3), J. spinosa (0.06), R. ferox (0.006), and S. mombin (0.02) (Table 3). In relation to the indices of infestation of fruit fly larvae per mass of fruit, the highest indices were found in C. gonocarpum (1.77), P. guineense (0.40), E. myrcianthes (0.25), P. guava (0.18), P. aculeata (0.17), P. giberi (0.19), P. alata (0.18), P. americana (0.14), R. ferox (0.11), C. guazumifolia (0.006), and J. spinosa (0.001) (Table 3).

**Discussion**

**Tephritidae**

*Anastrepha sororcula* was the most abundant species in *P. guava*, *C. guazumifolia*, and *P. guineense*. This species is commonly obtained from Myrtaceae, both wild and cultivated, in several studies (Bomfim et al. 2007; Marsaro Junior et al. 2013). In Mato Grosso do Sul, A. sororcula is the most abundant species in guava, as shown by Uchoa et al. (2002) and Uchoa and Nicádio (2010), results that are consistent with this research.

*Anastrepha serpentina* was recovered from fruits of Myrtaceae and Sapotaceae. This species attacks a wide diversity of fruits, and it has been recorded that it infested 7 families and 22 species (Zucchi & Moraes 2008), including sweet orange (*Citrus sinensis* L.) and tangerine (*C. reticulata* Blanco) (Rutaceae) (Lemos et al. 2011). Among the 22 hosts in which this species is recorded, 12 are Sapotaceae (Zucchi & Moraes 2008), indicating this family of plants as their preferred hosts. This explains the high abundance of *A. serpentina* in *C. gonocarpum*.

*Anastrepha fraterculus* was obtained from 4 host species in 2 families: *E. myrcianthes*, *P. guineense*, *C. guazumifolia* (all Myrtaceae), and *C. gonocarpum* (Sapotaceae) in descending order of abundance. This is the most polyphagous species of the genus *Anastrepha*, attacking 116 species of fruits from 27 families of plants (Zucchi & Moraes 2008). The discovery of *A. fraterculus* infesting *E. myrcianthes* emphasizes the importance of research on trophic interactions between tephritid species and fruit trees in conservation units. *Eugenia myrcianthes* is phylogenetically close to other co-generic species of genus Eugenia. In addition, *A. fraterculus* already had been reported in *Eugenia schomburgkii* Benth (Raga et al. 2005), *Eugenia desynterica* DC (Silva et al. 2010), and *Eugenia uniflora* L. (Veloso et al. 2012).

*Anastrepha barbiillini* is considered monophagous because *P. aculeata* is its only known host (Zucchi & Moraes 2008). This species was reported in a few inventories in other Brazilian states: São Paulo (Uramoto et al. 2004), Santa Catarina (Garcia & Norrbom 2011), and Rio de Janeiro (Ferrara et al. 2004). This species has the potential to be included in the list of fruit fly pests because at least 2 species of Cactaceae, which may be potential hosts, have been economically exploited in Brazil: pitahaya, *Hylocereus undatus* (Haw.) Britton & Rose, from Colombia, and the fig of India, *Opuntia ficus-indica* (L.) Miller (both Cactaceae). This last species already had been reported as being infesting by *A. fraterculus* (Junqueira et al. 2002; Torres et al. 2009; Leite et al. 2017).

*Anastrepha pseudoparallela* herein was recovered only from *P. alata*. This species is reported attacking 6 host fruits: 4 species of passion fruit (*P. alata*, *P. edulis*, *P. quadrangularis*, *P. elegans* Mant.), *M. indica*, and the Neotropical Myrtaceae *P. guajava* (Uramoto et al. 2004; Garcia & Norrbom 2011; Marsaro Junior 2014), suggesting a probable preference of this fruit fly species for Passifloraceae. In research on trophic associations between fruit flies and their host plants, *A. pseudoparallela* has been recovered only from fruits of the genus *Passiflora* (Garcia & Norrbom 2011; Araújo et al. 2018).

*Anastrepha striata* was recovered from 3 hosts: *P. guava*, *S. mombin*, and *J. spinosa*. This species usually is abundant in fruits of Myrtaceae, such as *P. guava* and *P. guineense* (Marsaro Junior 2011; Marsaro Junior et al. 2013), but in this study its infestation in guava was considered low, probably due to the competition with *A. sororcula*, which was quite abundant.

In an earlier study, there were reports of 2 species of *Anastrepha* (*A. fraterculus* and *A. turpiniinae* Stone) (Diptera: Tephritidae) infesting Caricaceae in Brazil (Martins et al. 1993). *Anastrepha striata* is reported here as an additional species that can infest Caricaceae. *Anastrepha striata* is polyphagous, with a wide range of hosts already reported, including cashew (*Anacardium occidentale* L.) (Anacardiaceae) (Jesus-Barros et al. 2012) and araçá (*Psidium cattleyanum* Sabine) (Myrtaceae) (Uchoa & Nicádio 2010).

**Table 3.** Infestation of larvae per number of fruit and flies per fruits from fruit tree species infested by frugivorous flies (Tephritidae and Lonchaeidae) in the interior of Parque Nacional da Serra da Bodoquena and surrounding areas (Bonito and Jardim, Mato Grosso do Sul), Brazil, from Jan 2017 to Feb 2018.

| Plant family | Fruit tree species | Third instar larvae (n) | Fruits (n) | Fruits weight (g) | Relative infestation (n per mass [g] of fruits) | Relative infestation (flies per fruits) |
|--------------|--------------------|------------------------|-----------|------------------|-----------------------------------------------|----------------------------------------|
| Anacardiaceae | Spondias mombin     | 2                      | 67        | 1,047            | 0.001                                         | 0.02                                   |
| Cactaceae    | Pereskia aculeata   | 51                     | 112       | 300              | 0.17                                          | 0.45                                   |
| Caricaceae   | Jacaranda spinosa   | 2                      | 31        | 1,632            | 0.001                                         | 0.06                                   |
| Lauraceae    | Persea americana    | 110                    | 8         | 7,832            | 0.014                                         | 13.75                                  |
| Myrtaceae    | Psidium guajava     | 191                    | 65        | 1,038            | 0.18                                          | 2.9                                    |
| *              | Campomanesia guazumifolia | 30              | 74        | 489              | 0.06                                          | 2.4                                    |
| *              | Psidium guineense   | 576                    | 75        | 1,417            | 0.40                                          | 7.6                                    |
| *              | Eugenia myrcianthes | 197                    | 133       | 779              | 0.25                                          | 1.48                                   |
| Passifloraceae| Passiflora alata    | 30                     | 10        | 1,649            | 0.018                                         | 3                                      |
| *              | Passiflora giberi    | 5                      | 17        | 257              | 0.019                                         | 0.29                                   |
| Rubiaceae    | Randia ferox        | 3                      | 498       | 160              | 0.018                                         | 0.006                                  |
| Sapotaceae   | Chrysophyllum gonocarpum | 279              | 235       | 157              | 1.77                                          | 1.18                                   |
The low level of abundance of *A. striata* in this study may result from the absence of its favorite hosts in the park, as well as local competition with other *Anastrepha* species. In native forests, where there is a tendency for more effective parasitism, this pest species may be disfavored. In addition, most of the hosts reported for *A. striata* are fruits with a large proportion of endocarp, such as guava (Uchoa et al. 2002), sour passion fruit (*Passiflora edulis* Sims) (*Passifloraceae*), and jackfruit (*Artocarpus heterophyllus* Lam.) (*Moraceae*) (Zucchi & Moraes 2008). These species are less common in natural environments (Uchoa et al. 2002; Bomfim et al. 2007, 2014).

*Anastrepha obliqua* was recovered from *S. mombin*, *C. guazumifolia*, and *E. myricanthes*. *Anastrepha obliqua* was reported previously in 50 hosts (Zucchi & Moraes 2008). Here, for the first time, *A. obliqua* is associated with *E. myricanthes*. This is the second most polyphagous species of the genus *Anastrepha*, being reported in several countries of South and Central America (Ovruski et al. 2009; Uchoa 2012; Sosa-Armenta et al. 2015). The low level of abundance of this species in the evaluated conservation unit may be related to the absence of its preferred hosts, such as cultivated species of *Myrtaceae*, *Anacardiaceae*, and *Oxiladeaceae*. *Anastrepha obliqua* has been reported as one of the most abundant species in guava, cashew, and star fruit (Uchoa 2012).

*Anastrepha elegans* was recovered from fruits of *C. gonocarpum*, its only known host. This association has been reported already by Garcia et al. (2008). There are few records of *A. elegans* in Brazil: Mato do Sul (Canesin & Uchoa 2007); São Paulo (Uramoto et al. 2004), Santa Catarina (Garcia et al. 2003), Paraná (Garcia 2003), and Rio Grande do Sul (Garcia et al. 2002). The low level of abundance of this species likely derives from its food habit (monophagy). It is believed that there are few individuals of *C. gonocarpum* in the park because it is a forest environment where fruit species are randomly distributed.

*Anastrepha zenildae* was recovered from 2 hosts: *C. guazumifolia* and *P. guineense*. It is considered a polyphagous species of great economic importance (Uchoa 2012). *Anastrepha zenildae* is reported infesting a wide range of hosts, including guava (Uchoa 2012), júá (*Ziziphus joazeiro* Mart.) (*Rhamnaceae*) (Canal et al. 1998), and guavira (*Campomanesia sessiflora* O. Berg) (*Myrtaceae*) (Uchoa et al. 2002).

In this study, the infestation by *A. zenildae* was considered low (n = 4), similar to the results of other inventories carried out in natural environments (Bomfim et al. 2007; Uchoa & Nicácio 2010). In native forests, such as conservation units, the abundance of available host fruits is lower than in commercial orchards, where they are found in great abundance and with uniform spatial distribution (Araújo et al. 2013). In addition, the same fruit tree may be host to several species of fruit flies, especially for the polyphagous species, such as *A. fraterculus* and *A. sororcula*, both found in great abundance in this study. In this study, the diversity of the tephritid species is directly related to the abundance of fruits in the samples: the fruit species with the highest number of fruit flies were those with greater abundance and biomass of fruit in the sample (*e.g.*, *C. gonocarpum*, *P. guineense*, and *E. myricanthes*).

*Anastrepha barbiellinii* was observed for the first time infesting *P. aculeata* in Mato Grosso do Sul. We also observed for the first time *A. serpentina*, *A. fraterculus*, and *A. obliqua* infesting fruits of *E. myricanthes* and *A. striata* in *J. spinosa*, and *A. zenildae* in *C. guazumifolia*.

**LONCHAEIDAE**

Lonchaeid species are as important as the tephritids in the infestation of many fruit species of economic interest. In certain plant taxa, such as *Citrus* spp. (* Rutaceae*) and several other native species, some species of *Neosilba* are primary invaders (Uchoa et al. 2002). Moreover, they also are indirectly responsible for the process of putrefaction of host fruits (Uchoa 2012).

Several species of the genus *Neosilba* are considered polyphagous, infesting a wide diversity of host plants in the Neotropical region. The 5 species considered the most important of this genus are *N. zadolicha*, *Neosilba pendula* (Bezz), *N. glaberrima*, *Neosilba perezi* (Romero & Ruppell), and *Neosilba inesperata* *Strikis & Prado* (all Diptera: Lonchaeidae) (Uchoa 2012).

*Neosilba zadolicha* can be considered a primary pest in many fruit species in several regions of the country. Among its hosts are coffee, *Coffeea arabica* L. (*Rubiaceae*) (*Strikis & Prado* 2005); araticum, *Annona rugulosa* (Schltdl.) H. Rainer (*Annonaceae*); aracá, *Psidium cattleianum* Sabine (*Myrtaceae*); and peach, *Prunus persica* (L.) Batsch. (*Rosaceae*) (Garcia & Norrbom 2011).

In this study, *N. zadolicha* was found infesting *P. americana* and *C. gonocarpum*. In the latter, it co-occurred with *A. serpentina*. No species of *Anastrepha* was recovered in *P. americana* in the present study, although *A. striata* has been reported already from avocado fruits (Uchoa et al. 2002). The results obtained here point out that some species of lonchaeids, such as *N. glaberrima* and *N. zadolicha*, apparently can be primary pests of avocado, in contrast to some reports (Araújo & Zucchi 2002; Souza-Filho et al. 2003) in which the lonchaeids were considered secondary or opportunistic pests, colonizing only fruits previously punctured by tephritids.

Recent research has associated *N. certa* with 15 hosts (Uchoa 2012 [11 hosts]; Gislotti et al. 2017 [2]; Santos et al. 2017 [2]). However, in this study, it was recovered only from *C. gonocarpum*. The low level of abundance of *N. certa* is possibly related to the interspecific competition with *A. serpentina* individuals (n = 234), which was more abundant in this host fruit.

*Neosilba glaberrima* is reported to infest 21 hosts (Uchoa 2012; Gislotti et al. 2017; Santos et al. 2017). In this research, this species was recovered only from *C. gonocarpum* and *P. americana*; both are new records. However, *N. zadolica*, *N. certa*, *N. glaberrima*, *N. pendula*, and *Neosilba parva* (Hennig) (*Diptera*: Lonchaeidae) have been reported from *P. americana* (Raga et al. 2015). *Neosilba* species have been found in greater abundance and frequency in avocado than tephritids (Aluja et al. 2004; Raga et al. 2011). Until this study, only *A. striata* was obtained from *P. americana* (Uchoa et al. 2002; Uchoa 2012), indicating this host fruit as preferred for *N. glaberrima*.

More research on lonchaeids and their host fruits in natural environments are needed, because knowledge about their biology and trophic associations with host plants and natural enemies are scarce in the Neotropical region. In this research we provide the first reports of *N. glaberrima* and *N. zadolicha* infesting *P. americana* and *N. certa* infesting *C. gonocarpum*.

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