



Direct Injury, Myiasis, Forensics

Flesh Flies (Diptera: Sarcophagidae) of Forensic Importance Collected From Pig Carcasses in the Cerrado of Northeastern Brazil

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Subject Editor: Jason Byrd

Received 21 August 2022; Editorial decision 15 December 2022.

Abstract

Sarcophagidae is a family of true flies frequently found colonizing carcasses and corpses as adults and/or larvae, therefore, they are of great forensic value in the medico-legal field. Thus, this study aims to inventory the sarcophagids species and describe their succession process in the decomposition of swine carcasses in the Cerrado (savanna-like vegetation), Brazilian Northeastern region. A total of 10,819 specimens were collected, belonging to 45 sarcophagid species. Of this total, one species was recently described (*Helicobia neuzalmeidae* Silva, Brasil, De-Souza & Carvalho-Filho), two [*Blaesoxipha (Acanthodthea) denieri* (Blanchard) and *Dexosarcophaga pusilla* Lopes] are new records for the Cerrado biome, five [*Argoravinia (Argoravinia) catiae* Carvalho Filho & Esposito, *B. (A.) denieri*, *Nephochaetopteryx orbitalis* (Curran & Walley), *Peckia (Sarcodexia) tridentata* (Hall) and *Tricharaea (Sarcophagula) ramirezi* (Lopes)] are new records for the Northeast region and eight are new records for the state of Maranhão. The species *A. (A.) catiae*, *Blaesoxipha (Gigantotheca) stallengi* (Lahille), *D. pusilla*, *H. neuzalmeidae*, *Lipoptilocnema misella* Lopes, *Oxysarcodexia bakeri* (Aldrich) and *Retrocitomyia retrocita* (Hall) were collected for the first time in pig carcasses. *Peckia (Sarcodexia) lambens* (Wiedemann) and *Oxysarcodexia thornax* (Walker) were the most abundant species. In both collection seasons, five species were carcasses pioneers at an early stage. The majority of species (42 spp.) were collected during the dry season, primarily during the black putrefaction (39 spp.) and butyric fermentation (30 spp.) stages. The greatest number specimens ($n = 6,484$) were recorded during the rainy season, at the butyric fermentation ($n = 2,517$) and black putrefaction ($n = 2,080$).

Key words: forensic entomology, new record, *Região dos Cocais*, Sarcophaginae

Sarcophagidae, or flesh flies, is the second biggest family of Calyptate flies (Diptera), with 117 genera and approximately 2,807 species distributed across the planet (Pape 2022). The Neotropical region houses around 939 species (Pape 2022), with 384 already documented for Brazil (Mello-Patiu et al. 2022). Adult sarcophagid species range in length from 3 to more than 16 mm, have a predominantly gray color, bare or plumose arista, dorsal region of the thorax with three longitudinal black bands, a row

of setae posteriorly on the meron, poorly developed subscutellum, and a checkered abdomen (Lopes 1954, Carvalho and Mello-Patiu 2008, Oliveira-Costa 2011).

Sarcophagidae are found in a variety of environments, ranging from forests to deserts (Rosa et al. 2011, Mello-Patiu et al. 2014, Sousa et al. 2016, Faria et al. 2018, Paseto et al. 2019, Madeira-Ott et al. 2022). Many species of various genera, however, prefer open, sunny environments, including anthropized places such as

clearings, meadows, and urbanized sites (Valverde-Castro et al. 2017, Buenaventura et al. 2021, Madeira-Ott et al. 2022).

Among the Calyptrate fly families, sarcophagids have the most diversified eating behavior during the larval stage (Dahlem 1991). Miltogramminae larvae are kleptoparasites that live in nests of solitary Hymenoptera. The biology of Paramacronychiinae and Sarcophaginae larvae is quite diverse, as they can be coprophagous, kleptoparasites in hymenopteran nests, predators of insect eggs, parasitoids of arthropods, and vertebrate ectoparasites that cause primary or secondary myiasis in humans and wild and domestic animals. Several species in the three subfamilies are sarcosaprophagous, meaning that their larvae feed on decaying tissues of invertebrates and vertebrates, including human cadavers (Shewell 1987, Dahlem 1991, Oliveira and Vasconcelos 2010, Pape and Dahlem, 2010, Vasconcelos et al. 2014, Ren et al. 2018, Yan et al. 2020, Guimarães et al. 2022).

Adult flesh flies can be collected in large numbers using traps that contain fruits, feces and decomposing animal tissue (Valverde-Castro et al. 2017, Carvalho-Filho et al. 2018, Barbosa et al. 2019, Andrade-Herrera et al. 2020, Buenaventura et al. 2021, Madeira-Ott et al. 2022). Many species, particularly those found in urban centers, carry pathogens on their external body surface or even in their digestive tract when they feed by coming into contact with various types of organic matter, such as *Staphylococcus aureus* (Rosenbach) (Bacillales, Staphylococcaceae), *Escherichia coli* (Escherich) (Enterobacteriales, Enterobacteriaceae), and *Shigella* spp. (Souza et al. 2021).

Due to the sarcosaprophagous feeding habits of several species, sarcophagids are of great importance in forensic entomology, since the development period of their larvae and/or the succession pattern of species, immature and/or adults, throughout the stages of decomposition of carcasses and corpses are used to assist in forensic processes, such as determining the time elapsed from death until the corpse is found, post-mortem interval (PMI) (Catts and Goff 1992, Oliveira-Costa 2011, Vairo and Moura 2021). It is more accurate to date the time passed from the initial days of the decomposition stages of carcasses and corpses if the developmental time of each larval instar until the emergence of adults is known. Knowledge of the succession pattern in communities by alternation or overlapping of species is the most appropriate method for prescribing the chronology of elapsed days when the stages are the most advanced in the decomposition (Carvalho and Linhares 2001, Oliveira-Costa 2011, Vairo and Moura 2021).

In this scenario, the increase in the number of studies on flies of the Sarcophagidae family in forensic entomology trials in the country, which is very diverse in terms of biogeographic zones, phytophysionomies, and climate, has resulted in the discovery of new species and records, expanding their distributions and knowledge about the temporal succession of species in carcasses in various regions of Brazil (Barros et al. 2008, Rosa et al. 2011, Mello-Patiu et al. 2014, Faria et al. 2018, Paseto et al. 2019). With an area of 2,036,448 km², the Cerrado is the second largest biome in South America. It spans all five regions of Brazil, encompassing territories in thirteen states and the Distrito Federal. It belongs to the seasonal tropical forest category, which is distinguished by high temperatures and pronounced wet, rainy, or dry seasons over the year (Relyea and Ricklefs 2021). In the Northeast, specifically in the state of Maranhão, the Cerrado is located in a unique position in the country, as it is located between the Amazon Forest biome, to the west and south, and between the Caatinga to the east. Furthermore, the biome has several phytophysionomies, including Campo Limpo, Campo Suco, Cerrado stricto sensu, and Cerrado (Nascimento and Ribeiro 2017).

Studies on inventories and community structures of sarcosaprophagous sarcophagids collected with traps containing rotten bovine lung were carried out in the Cerrado of Maranhão by Sousa et al. (2016) and Nascimento et al. (2021), which found about 50% of species in common. This significant difference in species composition is likely due to the fact that Sousa et al. (2016) conducted experiments in Cerrado areas further south of the state, where the Amazon Forest has a greater influence, whereas Nascimento et al. (2021) performed experiments in Cerrado areas further east of the state, where the Caatinga has a greater influence. Traps baited with bovine lungs have been effective for capturing pioneer flies during the colonization of decomposing organic waste of animal origin. However, this strategy has not been successful in collecting late flies, which often appear three or more days into the decomposition process (Vasconcelos and Araujo 2012). These methodological factors influence the outcomes of sarcophagid individual composition, species richness, and abundance, which are significant for forensic studies that require information from the earliest stage to skeletonization.

As a result, this study aims to inventory the species of sarcophagids and describe their successional process during the stages of decomposition of swine carcasses in the Cerrado biome in Brazil's Northeast region. Furthermore, we present new sarcophagid species records for the Cerrado, the Northeast region, and the state of Maranhão, as well as information on species collected for the first time around swine carcasses.

Material and Methods

Study Place

The current study's data were based on material collected in a Cerrado primary vegetation in the Municipal Environmental Protection Area of Inhamum (Área de Proteção Ambiental Municipal do Inhamum – Inhamum APA), whose coordinates are 04° 53'45.7" S and 43° 26'21.8" W, in the rural area of the municipality of Caxias, in the eastern state of Maranhão, in Brazil's Northeast region (Fig. 1). The municipality's climate is classified as sub-humid dry (Thornthwaite 1948). The collections were conducted from July to August 2010 (dry season) and March to April 2011 (rainy season), with a total rainfall of 1.7 mm (characteristic of the dry season) and 93.8 mm (characteristic of the rainy season) recorded for Caxias (Data provided by the Estação Meteorológica e Climatológica Principal de Caxias – MA, Instituto Nacional de Meteorológica – INMET 2010, 2011).

In the Inhamum APA, which covers 3,564 ha (Barros 2012), the average temperature was 27.5°C (SD = 3.64) and the average relative humidity was 71% (SD = 15.94) in the dry season, and 27°C (SD = 2.83) and 82% (SD = 11.82) in the rainy season (Data obtained through measurements carried out daily at the site of the experiments using a digital thermo-hygrometer). The phytophysionomy of the Cerrado at the study site includes a variety of sedges [for example, *Cyperus aggregatus* (Willd.), *Cyperus distans* (Linnaeus), and *Cyperus laxis* Lam. (Poales, Cyperaceae)], shrubs, and trees ranging in size from small to medium, scattered among themselves or in small agglomerations, forming thickets. The trees usually found in the region are cashew tree (*Anacardium occidentale* Linnaeus; Anacardiaceae), mastic (*Myracrodruon urundeuwa* Allem; Sapindales, Anacardiaceae), pink lapacho (*Tabebuia impetiginosa* (Mart. ex. DC.); Lamiales, Bignoniaceae), pequi (*Caryocar coriaceum* Wittm.; Malpighiales, Caryocaraceae) and candeia (*Plathymenia reticulata* Benth.; Fabales, Fabaceae). Furthermore, the APA contains many springs that form several

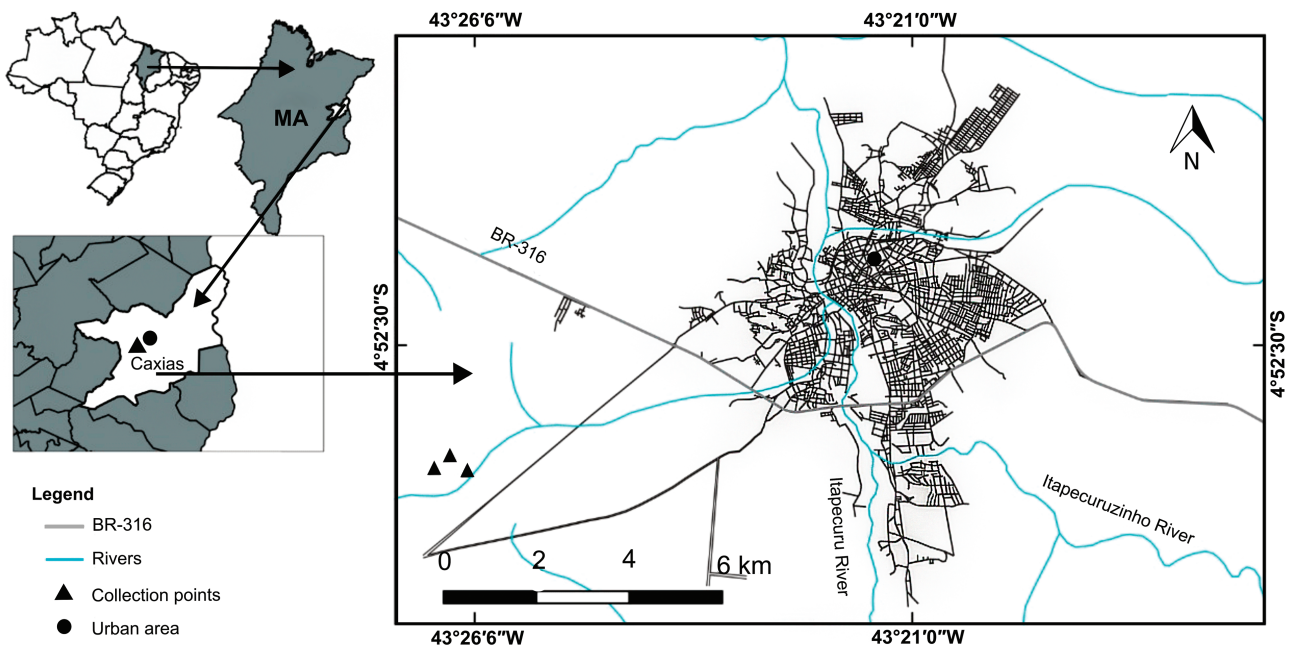


Fig. 1. Map with the collection points of sarcophagids in the Cerrado of the Área de Proteção Ambiental Municipal do Inhamum, in the municipality of Caxias, MA, Brazil. Source: IBGE (2010, modified by P. R. C. Santos 2021).

streams, which have the phytophysiognomy of a gallery forest in their surroundings, along their paths, with medium to large trees, such as buriti (*Mauritia flexuosa* Linnaeus; Arecales, Arecaceae) and babassu (*Attalea speciosa*, Mart. ex. Spreng; Arecales, Arecaceae), which are characteristic of the Cocal Forest (Barros 2012).

Methodological Procedure

Six pig (*Sus scrofa* L.) carcasses weighing 12 kg each were utilized, three in each of the two collection seasons. The carcasses were placed in metallic cages beneath the shade of trees and at least 500 m apart. The Bornemissza (1957) classification was employed to identify the stages of decomposition of the carcasses: initial decay, putrefaction, black putrefaction, butyric fermentation, and dry decay, or skeletonization. For fly collection, suspended traps (adapted from Rafael and Gorayeb 1982) were put 30 cm above the ground on the cages (Fig. 2). Daily collections were made in the morning.

The sarcophagids were preserved in 92.8% alcohol or mounted on pins, stored in entomological drawers (which were killed using ethyl acetate in a lethal dose), and deposited in the Coleção Zoológica do Maranhão (CZMA), Universidade Estadual do Maranhão (UEMA), Caxias Campus, MA, Brazil. The identifications were made by analyzing the morphology and external body anatomy, particularly the male genitalia, which were exposed and, in some cases, separated from the body for greater view of the components. Male species were identified using a stereomicroscope, with the help of specific identification keys, descriptions, and revision works (Lopes and Downs 1949; Lopes 1954, 1956, 1982; Mello 1996; Mello-Patiu 1996, 2002; Guimarães 2004; Carvalho and Mello-Patiu 2008; Pape and Dahlem 2010; Vairo et al. 2011; Carvalho-Filho and Esposito 2012; Buenaventura and Pape 2013; Carvalho-Filho et al. 2014, 2017, 2021; Mello-Patiu and Salazar-Souza 2016; Mulieri et al. 2016; Souza et al. 2020; Barbosa et al. 2021; Camargo 2021), and by comparison with species already identified from the entomological collection of the Museu Paraense Emílio Goeldi (MPEG), in Belém, PA, as well as the CZMA. Only male specimens were



Fig. 2. Suspended trap (1.50 m side edge and 1.60 m high), placed at a height of 30 cm from the ground, over the cage (110 cm long, 85 cm wide, and 85 cm high; and 3 by 3 cm mesh screen) containing a pig carcass, utilized to collect sarcophagids from the Cerrado in the Área de Proteção Ambiental Municipal do Inhamum, in the municipality of Caxias, MA, Brazil.

identified at a specific level because identification is primarily based on male genitalia features. The witness material of the present research was deposited in these two collections.

The sarcophagids investigated in this study were deposited at CZMA between 2010 and 2011. This material was obtained from experiments with swine carcasses that were killed without suffering or pain using a firearm projectile (20 gauge) in the occipital region of the head (according to the general guidelines of the Ethics Committee on the Use of Animals - CEUA), which were carried out in the APA of Inhamum in 2010 and 2011 with the authorization of the Secretaria Municipal de Meio Ambiente e Preservação dos Recursos Naturais de Caxias, MA (SEMUMA), and through the License (No. 12417) issued by the Sistema de Autorização e Informação em Biodiversidade - SISBIO.

Data Analysis

We created rarefaction curves to estimate the number of species based on the number of specimens collected (Gotelli and Colwell 2001). We used the iNEXT package (Hsieh et al. 2016) to calculate the rarefaction and generate curves with interpolation (rarefaction) and extrapolation (Chao and Jost 2012) to compare data from the dry and rainy seasons with different numbers of specimens.

Results

A total of 10,819 specimens were sampled and studied, with 4,335 individuals and 42 species gathered during the dry season; and 6,484 individuals and 37 species collected during the rainy season, representing a total of 13 genera and 45 species when the two seasons were considered together (Table 1). The rarefactions showed that although there are fewer specimens collected in the dry season, it has a greater diversity of species. However, analyzing the extrapolation, it can be seen that there is a tendency for the diversity of the dry and rainy seasons to be similar as the number of specimens increases (Fig. 3). One species (*Helicobia neuzalmeidae* Silva, Brasil, De-Souza and Carvalho-Filho, 2022) belonged to a new species that was recently named (Silva et al. 2022); two species [*Dexosarcophaga pusilla* Lopes, 1975 and *Blaesoxipha (Acanthodtheba) denieri* (Blanchard, 1939)] are new records for the Cerrado; five species [*Argoravinia (Argoravinia) catiae* Carvalho Filho and Esposito, 2012, *B. (A.) denieri*, *Nephochaetopteryx orbitalis* (Curran & Walley, 1934), *Peckia (Sarcodexia) tridentata* (Hall, 1937) and *Tricharaea (Sarcophagula) ramirezi* (Lopes, 1990)] are new records for the Northeast area of Brazil; and eight species [*Dexosarcophaga lenkoi* Lopes, 1968, *Dexosarcophaga paulistana* (Lopes, 1968), *D. pusilla*, *Dexosarcophaga transita* Townsend, 1917, *Lipoptilocnema salobrensis* Lopes, 1942, *Oxysarcodexia carvalhoi* Lopes, 1946, *Oxysarcodexia parva* Lopes, 1946 and *Oxysarcodexia simplicoides* (Lopes, 1933)] are new records for the state of Maranhão. The species *A. (A.) catiae*, *Blaesoxipha (Gigantotheca) stallengi* (Lahille, 1907), *D. pusilla*, *H. neuzalmeidae*, *Lipoptilocnema misella* Lopes, 1939, *Oxysarcodexia bakeri* (Aldrich, 1916) and *Retrocitomyia retrocita* (Hall, 1933) were collected for the first time in pig carcasses (Table 1).

The genera with the most species were *Oxysarcodexia* Townsend, 1917 (12 spp.), *Peckia* Robineau-Desvoidy 1830 (8 spp.), and *Dexosarcophaga* Townsend, 1917 (6 spp.). *Peckia (Sarcodexia) lambens* (Wiedemann, 1830) was the most abundant species, accounting for 29.99% of the entire sample, followed by *Oxysarcodexia thornax* (Walker, 1849) (22.01%), *Peckia (Euboettcheria) collusor* (Curran & Walley, 1934) (14.94%), *Oxysarcodexia timida* (Aldrich, 1916) (10.22%), and *Dexosarcophaga carvalhoi* (Lopes, 1980) (5.27%). The other species accounted for 17.57% of the overall sample. The species *A. (A.) catiae*, *B. (G.) stallengi*, *Dexosarcophaga (Bezzisca) ampullula* (Engel, 1931), *Dexosarcophaga lenkoi* (Lopes, 1968), *D. transita*, *H. neuzalmeidae*, *O. bakeri*, and *T. (S.) ramirezi* were only found during the dry season and the species *D. pusilla*, *L. salobrensis*, and *Oxysarcodexia xanthosoma* (Aldrich, 1916) were only identified during the rainy season. The other species, the majority (34 spp.), appeared in both seasons (Table 1).

Decomposition of swine carcasses was observed in five stages, with a decomposition duration of 10 d on average in both dry (SD = 0) and rainy (SD = 1) seasons. The initial decay stage, putrefaction, black putrefaction, butyric fermentation, and dry decay stages

lasted, on average, 24 h (SD = 0), 24 h (SD = 0), 72 h (SD = 0), 72 h (SD = 0), and 48 h (SD = 0) in the dry season, respectively; and 24 h (SD = 0), 48 h (SD = 0), 48 h (SD = 0), 72 h (SD = 1), and 48 h (SD = 0) in the rainy season, respectively. During the dry season, the black putrefaction (39 spp. and 55.4% of total specimens collected) and butyric fermentation (with 30 spp. and 29.5% of the total of collected specimens) stages showed greater species richness and abundance. The species *D. carvalhoi*, *Oxysarcodexia avuncula* (Lopes, 1933), *O. thornax*, *O. timida*, and *Ravinia belforti* (Prado & Fonseca, 1932) were pioneers in the process of carcass colonization and were the only ones detected in the initial and all subsequent stages of carcass decomposition. *Helicobia neuzalmeidae* was the only one that only appeared during the putrefaction stage. Seven species [*B. (G.) stallengi*, *D. lenkoi*, *Helicobia aurescens* (Townsend, 1927), *Peckia (Euboettcheria) anguilla* (Curran & Walley, 1934), *Peckia (Peckia) chrysostoma* (Wiedemann, 1930), *Ravinia effrenata* (Walker, 1861) and *Sarcofartiopsis cuneata* (Townsend, 1935)] were found only in the black putrefaction stage. Only during the butyric fermenting stage *Oxysarcodexia bakeri* (Aldrich, 1916) was obtained. The other species were found in two (13 species), three (7 species), or four (8 species) stages of decomposition (Table 1).

During the rainy season, the butyric fermentation stage (with 32 spp. and 38.82% of the total specimens collected) showed the most species richness and abundance; the second with the highest species richness and abundance were putrefaction (with 29 spp. and 19.4% of the total specimens collected) and black putrefaction (with 28 spp. and 32.08% of the total specimens collected), respectively. Except for *O. avuncula*, which was not found in the butyric fermentation and dry decay stages, the species *D. carvalhoi*, *O. avuncula*, *O. thornax*, *P. (E.) collusor*, and *P. (S.) lambens* were pioneers in the process of carcass colonization and the only ones found in the initial stage, as well as all other carcass decomposition stages. Only *D. pusilla* and *O. simplicoides* were found during the putrefaction stage. Moreover, only in the black putrefaction stage *Oxysarcodexia intona* (Curran & Walley, 1934) was found. Only at the butyric fermentation stage did *B. (A.) denieri*, *D. paulistana*, *O. xanthosoma*, and *Titanogrypa (Cuculomyia) larvicida* (Lopes, 1935) appear. *Sarcofartiopsis cuneata* was the only one that only appeared during the dry decay stage. The other species appeared in two (3 spp.), three (5 spp.), or four (16 spp.) decomposition stages (Table 1).

Discussion

From a list of 38 species based on species recovered from carcasses and corpses (Vairo and Moura 2021), 19 species were obtained in the present paper [*H. aurescens*, *Helicobia pilifera* Lopes, 1939, *Oxysarcodexia amorosa* (Schiner, 1868), *Oxysarcodexia angrensis* (Lopes, 1933), *O. avuncula*, *O. intona*, *O. parva*, *O. thornax*, *O. timida*, *P. (E.) anguilla*, *P. (E.) collusor*, *P. (P.) chrysostoma*, *P. (S.) lambens*, *Peckia (Squamotodes) ingens* (Walker, 1849), *Peckia (Squamotodes) trivittata* (Curran, 1927), *R. belforti*, *T. (C.) larvicida*, *Tricharaea (Sarcophagula) canuta* (Wulp, 1896) e *Tricharaea (Sarcophagula) occidua* (Fabricius, 1794)] have been identified as being of forensic value for South America. Another 19 [*B. (A.) denieri*, *D. ampullula*, *D. carvalhoi*, *D. lenkoi*, *D. paulistana*, *D. transita*, *Helicobia pilipleura* Lopes, 1939, *L. salobrensis*, *N. orbitalis*, *O. carvalhoi*, *Oxysarcodexia modesta* Lopes, 1946, *O. simplicoides*, *O. xanthosoma*, *Peckia (Peckia) pexata* (Wulp, 1895), *P. (P.) tridentata*, *R. effrenata*, *Retrocitomyia mizuguchiana* Tibana & Xerez, 1985, *S. cuneata* e *T. (S.) ramirezi*] species have been observed colonizing swine carcasses in Brazil (Barros et al. 2008, Barbosa et al. 2009,

Table 1. Species of Sarcophagidae and abundance (n) of male specimens distributed according to the stages of decomposition of pig carcass and seasons in an area of Cerrado in the Área de Proteção Ambiental Municipal do Inhamum, Caxias, Maranhão, Brazil

Species	Decomposition stages DS					Total DS	Decomposition stages RS					Total RS	Total DS + RS
	I	II	III	IV	V		I	II	III	IV	V		
<i>Argoravinia (Argoravinia) catiae</i> Carvalho Filho & Esposito, 2012 * [®]	0	0	6	3	0	9	0	0	0	0	0	0	9
<i>Blaesoxipha (Acanthodotheca) denieri</i> (Blanchard, 1939) ^{α *}	0	0	3	1	1	5	0	0	0	1	0	1	6
<i>Blaesoxipha (Gigantotheca) stallengi</i> (Lahille, 1907) [®]	0	0	3	0	0	3	0	0	0	0	0	0	3
<i>Dexosarcophaga (Bezzisca) ampullula</i> (Engel, 1931)	0	0	1	1	0	2	0	0	0	0	0	0	2
<i>Dexosarcophaga carvalhoi</i> (Lopes, 1980)	5	19	363	110	20	517	1	22	14	14	2	53	570
<i>Dexosarcophaga lenkoi</i> Lopes, 1968 **	0	0	1	0	1	2	0	0	0	0	0	0	2
<i>Dexosarcophaga paulistana</i> (Lopes, 1968) **	0	2	1	0	0	3	0	0	0	1	0	1	4
<i>Dexosarcophaga pusilla</i> Lopes, 1975 ^{α **} [®]	0	0	0	0	0	0	0	2	0	0	0	2	2
<i>Dexosarcophaga transitia</i> Townsend, 1917 **	0	1	1	0	0	2	0	0	0	0	0	0	2
<i>Helicobia aurescens</i> (Townsend, 1927)	0	0	3	0	0	3	0	5	0	1	0	6	9
<i>Helicobia neuzalmeidae</i> Silva, Brasil, De-Souza & Carvalho-Filho, 2022 [®]	0	1	0	0	0	1	0	0	0	0	0	0	1
<i>Helicobia pilifera</i> Lopes, 1939	0	4	3	0	2	9	0	6	4	7	0	17	26
<i>Helicobia pilipleura</i> Lopes, 1939	0	0	1	1	0	2	0	15	4	6	1	26	28
<i>Lipoptilocnema misella</i> Lopes, 1939 [®]	0	0	0	2	1	3	0	2	4	3	0	9	12
<i>Lipoptilocnema salobrensis</i> Lopes, 1942 **	0	0	0	0	0	0	0	3	2	0	1	6	6
<i>Nephochaetopteryx orbitalis</i> (Curran & Walley, 1934) *	0	0	5	2	0	7	0	11	10	7	1	29	36
<i>Oxysarcodexia amorosa</i> (Schiner, 1868)	0	3	90	22	10	125	0	22	23	12	1	58	183
<i>Oxysarcodexia angrensis</i> (Lopes, 1933)	0	3	28	7	4	42	0	4	20	33	4	61	103
<i>Oxysarcodexia avuncula</i> (Lopes, 1933)	1	7	46	20	6	80	1	0	2	2	0	5	85
<i>Oxysarcodexia bakeri</i> (Aldrich, 1916) [®]	0	0	0	1	0	1	0	0	0	0	0	0	1
<i>Oxysarcodexia carvalhoi</i> Lopes, 1946 **	0	5	68	20	5	98	0	40	50	30	4	124	222
<i>Oxysarcodexia intona</i> (Curran & Walley, 1934)	0	0	2	2	0	4	0	0	1	0	0	1	5
<i>Oxysarcodexia modesta</i> Lopes, 1946	0	0	3	1	0	4	0	1	5	5	1	12	16
<i>Oxysarcodexia parva</i> Lopes, 1946 **	0	0	11	10	8	29	0	2	2	6	2	12	41
<i>Oxysarcodexia simplicoides</i> (Lopes, 1933) **	0	0	8	3	2	13	0	1	0	0	0	1	14
<i>Oxysarcodexia thornax</i> (Walker, 1849)	1	40	644	546	171	1402	8	179	370	356	66	979	2,381
<i>Oxysarcodexia timida</i> (Aldrich, 1916)	7	33	411	170	68	689	0	53	169	174	21	417	1,106
<i>Oxysarcodexia xanthosoma</i> (Aldrich, 1916)	0	0	0	0	0	0	0	0	0	1	0	1	1
<i>Peckia (Euboettcheria) anguilla</i> (Curran & Walley, 1934)	0	0	1	0	0	1	0	5	5	5	2	17	18
<i>Peckia (Euboettcheria) collusor</i> (Curran & Walley, 1934)	0	23	484	177	78	762	1	134	294	335	90	854	1,616
<i>Peckia (Peckia) chrysostoma</i> (Wiedemann, 1930)	0	0	1	0	0	1	0	3	12	9	1	25	26
<i>Peckia (Peckia) pexata</i> (Wulp, 1895)	0	1	11	6	0	18	0	57	101	75	13	246	264
<i>Peckia (Sarcodexia) lambens</i> (Wiedemann, 1830)	0	1	26	32	20	79	14	641	907	1258	346	3,166	3,245
<i>Peckia (Sarcodexia) tridentata</i> (Hall, 1937) *	0	0	5	4	0	9	0	4	3	3	0	10	19
<i>Peckia (Squamatoses) ingens</i> (Walker, 1849)	0	0	3	3	5	11	0	7	5	5	0	17	28

Table 1. Continued

Species	Decomposition stages DS					Total DS	Decomposition stages RS					Total RS	Total DS + RS
	I	II	III	IV	V		I	II	III	IV	V		
<i>Peckia (Squamatodes) trivittata</i> (Curran, 1927)	0	3	7	5	5	20	0	18	13	8	1	40	60
<i>Ravinia belforti</i> (Prado & Fonseca, 1932)	1	4	98	89	49	241	0	1	20	45	14	80	321
<i>Ravinia effrenata</i> (Walker, 1861)	0	0	2	0	0	2	0	0	1	3	0	4	6
<i>Retrocitomyia mizuguchiana</i> Tibana & Xerez, 1985	0	1	3	2	0	6	0	1	2	1	1	5	11
<i>Retrocitomyia retrocita</i> (Hall, 1933) ®	0	1	1	0	0	2	0	1	0	3	0	4	6
<i>Sarcofartiopsis cuneata</i> (Townsend, 1935)	0	0	2	0	0	2	0	0	0	0	1	1	3
<i>Titanogrypa (Cuculomyia) larvicida</i> (Lopes, 1935)	0	0	6	1	0	7	0	0	0	1	0	1	8
<i>Tricharaea (Sarcophagula) canuta</i> (Wulp, 1896)	0	10	9	4	1	24	0	2	2	14	7	25	49
<i>Tricharaea (Sarcophagula) occidua</i> (Fabricius, 1794)	0	9	33	31	11	84	0	13	35	93	27	168	252
<i>Tricharaea (Sarcophagula) ramirezi</i> (Lopes, 1990) *	0	0	9	2	0	11	0	0	0	0	0	0	11
TOTAL	15	171	2,403	1,278	468	4,335	25	1,255	2,080	2,517	607	6,484	10,819

Note: DS = dry season; and RS = rainy season. Carcass decomposition stages: I = initial decay, II = putrefaction, III = black putrefaction, IV = butyric fermentation, and V = dry decay. New record for: Cerrado (°), Northeast region (*), Maranhão (**). First record in pig carcass (®). Decomposition stages in which each species was found in two seasons are highlighted in gray. Species occurring only in one of the seasons, dry or rainy, were highlighted in red and blue, respectively.

Rosa et al. 2011, Bitar et al. 2013, Alves et al. 2014, Mello-Patiu et al. 2014, Vairo et al. 2014, Ries and Blochtein (2015), Faria et al. 2018, Paseto et al. 2019, Madeira-Ott et al. 2022). In addition to these, seven species, which will be discussed further throughout the article, were recorded for the first time in swine carcasses. This knowledge contributes to enhance the number of species that can aid in the resolution of forensic processes in each region of the country, particularly in the Cerrado in the Northeast area.

Only two *D. pusilla* specimens were collected in the putrefaction stage of the carcasses during the rainy season, and this is the first report of this species visiting pig carcass, as it had previously only been found in traps with fermented banana and bovine lung (Carvalho-Filho et al. 2018). This is also the first time this species has been found in the Cerrado and the state of Maranhão. Until then, this species had only been recorded for Caatinga (desertic environment) in the state of Ceará (Northeast Brazil), Amazon Forest in the state of Pará (Northern Brazil), Costa Rica, Panama, and Peru (Pape 1996, 2022; Carvalho-Filho et al. 2018).

Few *B. (A.) denieri* specimens were obtained between the fourth and ninth day of decomposition, in the stages of black putrefaction ($n = 3$), butyric fermentation ($n = 2$), and dry decay phase ($n = 1$). In a forensic study conducted in the Pampa biome of Rio Grande do Sul, in the Southern region of Brazil, Ries and Blochtein (2015) recorded for the first time the specimens of *B. (A.) denieri* visiting swine carcasses and, as in the current study, obtained few specimens of this species ($n = 3$), classifying it as rare, in the stage of black putrefaction. *Blaesoxipha (A.) denieri* is a Neotropical species found in Central America and Southern South America. In Central America, it has already been recorded in the Costa Rican rainforest; and in South America, it has already been registered in the Pampas of Argentina and Paraguay, as well as in the Atlantic Forest and Pampa biomes of Brazil's Southeast (Espírito Santo, Rio de Janeiro, and São Paulo) and South states (Paraná, Rio Grande do Sul, and Santa Catarina) (Pape 1996, 2022; Mulieri et al. 2010; Ries and Blochtein 2015; Mello-Patiu et al. 2022). Therefore, the current study provides information

on the second occurrence of *B. (A.) denieri* in swine carcasses and the first record in the Cerrado biome in Brazil's Northeast region.

Two new species records for the Northeast region of Brazil, *A. (A.) catiae* and *T. (S.) ramirezi*, were collected only during the dry season. This is the first report of *A. (A.) catiae* visiting pig carcasses, throughout the stages of black putrefaction and butyric fermentation. This species appears to be associated with open formations such as the Cerrado and white-sand vegetation, where it was captured in traps baited with fermented banana and bovine lung in eastern Pará state, in the Brazilian Amazon (Carvalho-Filho and Esposito 2012; Carvalho-Filho et al. 2018, 2022). *Tricharaea (S.) ramirezi* had already been identified in Amazon Rainforest areas in Northern Brazil (Prudente et al. 2008), Cerrado areas in Central Brazil (Rosa et al. 2011), and Roraima, a border area between Brazil and Venezuela (Riccardi et al. 2022). Thus, it can be found in both forested and savannah regions. Rosa et al. (2011) found this species visiting pig carcasses only during the dry season in Cerrado areas of Minas Gerais, Brazil's Southeastern state.

The other two new species for the Northeast, *N. orbitalis* and *P. (S.) tridentata*, were collected during both dry and rainy seasons. *Nephochaetopteryx orbitalis*, which has been recorded only for Guyana (Bartica) and Brazil, in the North (Amazon Forest, in the state of Pará) and Southeast areas (Atlantic Forest and in the Cerrado, in the states of Rio de Janeiro and Minas Gerais, respectively) (Paseto et al. 2019, Carvalho-Filho et al. 2021), was also recorded in the present study in the Northeast region, in a Cerrado area, visiting swine carcasses from the putrefaction stage to skeletonization. *Peckia (S.) tridentata* has been recorded only in South America, specifically in Brazil (in areas of the Amazon forest in the North (in the states of Amazonas and Roraima); and in the Cerrado, in the Midwest (Mato Grosso), Southeast (Minas Gerais), and Northeast [Maranhão (data from the current study)], Colombia (Amazonas and Meta), and Ecuador (Napo) (Buenaventura and Pape 2013, Vairo et al. 2014, Faria et al. 2018, Riccardi et al. 2022). *Peckia (S.) tridentata* was frequently collected by Faria et al. (2018) in the

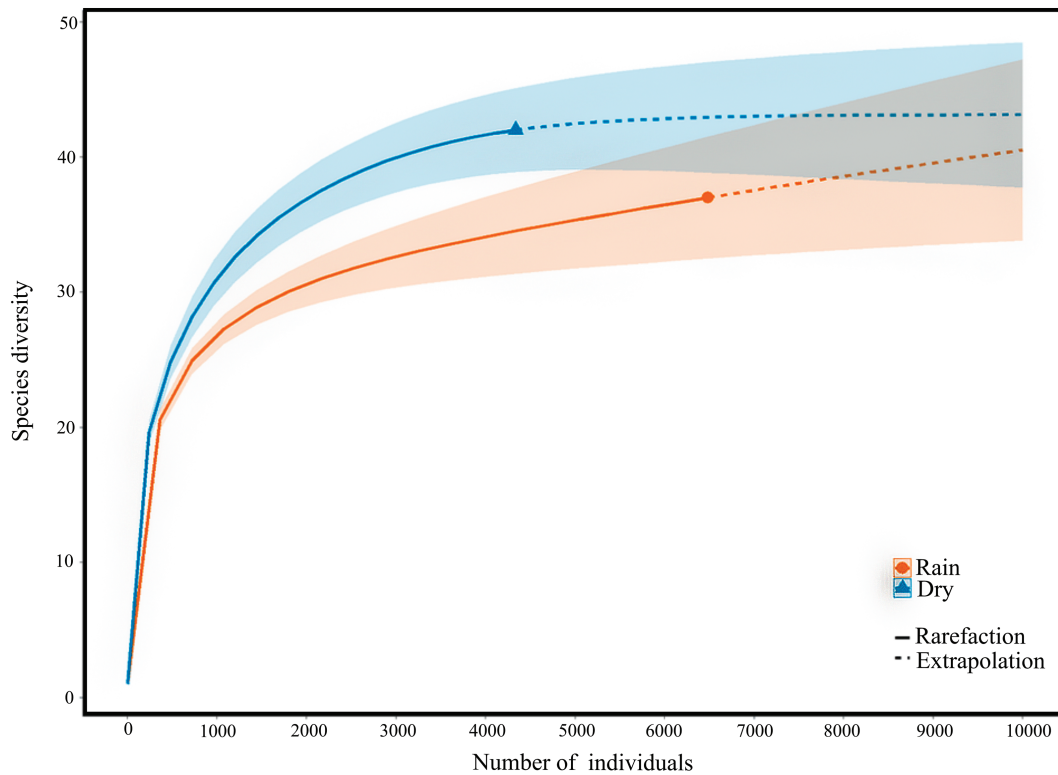


Fig. 3. Rarefaction curves containing the number of species expected based on the number of individuals collected in the dry and rainy seasons.

Cerrado of the state of Minas Gerais, in the country's Southeast area, colonizing swine carcasses in the dry and rainy seasons. In central Amazonia, *P. (S.) tridentata* is indicated by Vairo et al. (2014) as a species of forensic potential.

Another seven species, in addition to *D. pusilla*, which are new records for the state of Maranhão, have a wide distribution throughout Brazil (*D. lenkoi*, *D. paulistana*, *D. transita*, *L. salobrensis*, *O. carvalhoi*, *O. parva*, and *O. simplicoides*) as well as in other Neotropical countries (*D. transita*, *L. salobrensis*, *O. carvalhoi*, *O. parva*, and *O. simplicoides*) and Nearctic regions (*D. transita*) (Pape 1996, 2022). Four of these species (*D. lenkoi*, *D. paulistana*, *D. transita*, and *L. salobrensis*) were rare (less than six specimens) in the present study and were detected at the stages of black putrefaction and butyric fermentation of the carcasses, as noted by Barros et al. (2008) in a Cerrado area in the Distrito Federal for the species *D. lenkoi* and *D. paulistana*.

Regarding the other three species recorded for the first time in Maranhão from the genus *Oxysarcodexia*, which has more species that visit swine carcasses, as also confirmed in various studies on forensic entomology carried out in Brazil (Barros et al. 2008, Rosa et al. 2011, Mello-Patiu et al. 2014, Faria et al. 2018, Paseto et al. 2019, Toma et al. 2020), *O. carvalhoi* was a common visitor in the carcasses ($n = 222$), being frequent and abundant from the putrefaction stage to the dry decay stage in both seasons. These findings for *O. carvalhoi* were comparable to those observed by Paseto et al. (2019) in investigations conducted with pig carcasses in Cerrado areas of the state of Minas Gerais in Brazil's Southeast region. *Oxysarcodexia parva* was likewise a frequent and prolific visitor to carcasses during the dry season ($n = 29$), emerging in the black putrefaction to dry stage; however, it was scarce during the rainy season ($n = 12$), appearing in the putrefaction to dry stage. *Oxysarcodexia simplicoides*, on the other hand, was not abundant, with the majority of specimens ($n = 13$)

appearing in the last three stages of carcass decomposition in the dry season and only one specimen in the putrefaction stage in the rainy season, making it a rare species in carcasses for this period in the Cerrado.

In addition to the previously mentioned species, another four [*L. misella*, *B. (G.) stallengi*, *R. retrocita*, and *O. bakeri*] were recorded visiting swine carcasses for the first time. The natural history of *L. misella* adults is little documented in the literature. The first information on this aspect was recently presented by Nascimento et al. (2021), in a faunal inventory study carried out in the state of Maranhão, in which they collected *L. misella* in a trap baited with bovine lung in an area of riparian forest. The remaining three species [*B. (G.) stallengi*, *R. retrocita*, and *O. bakeri*] were found in a variety of baits. *Blaesoxipha (G.) stallengi* was collected in the Northeast region in traps baited with bovine lung in Cerrado areas (Sousa et al. 2016, Nascimento et al. 2021) and riparian forest in the state of Maranhão (Nascimento et al. 2021); in human feces, fish (sardines), bovine spleen and in rat carcass in Caatinga in the states of Paraíba and Pernambuco (Oliveira and Vasconcelos 2018, Barbosa et al. 2019). *Retrocitomyia retrocita* was found in fermented banana baits and rotting bovine lung in Campina areas of the state of Pará, in the North region (Carvalho-Filho et al. 2018); and in human feces, fish (sardines), and bovine spleen in Caatinga in the states of Paraíba and Pernambuco, in the Northeast region (Barbosa et al. 2019). While *O. bakeri* was collected from bovine lung in swamp areas in the state of Maranhão (Sousa et al. 2016); beef, chicken offal, and sardines on the coast of Pernambuco state (Northeast Brazil) (Barbosa et al. 2015, 2017); in fermented banana, in an area of Campina in Pará state (Brazilian Amazon) (Carvalho-Filho et al. 2018); and in human feces, in urban, rural and forested areas in Colombia (Valverde-Castro et al. 2017).

When compared to other studies (Barros et al. 2008, Rosa et al. 2011, Paseto et al. 2019), carcass decomposition was rapid and

had the same duration in both periods, with the black putrefaction and butyric fermentation stages having the longest duration, around three days, except for the black putrefaction in the rainy season, which lasted two days. Souza and Linhares (1997) obtained a decomposition time of 12 d for a 10 kg carcass in the rainy season in a forest fragment in Campinas, São Paulo state; and Madeira-Ott et al. (2022) recorded a decomposition period of 10 d for a 12 kg carcass in the dry season in a rural environment in a forest fragment in state of Rio Grande do Sul. The rainy season's frequent and heavy rainfall, along with high relative humidity and temperature, may have accelerated the decomposition of the black putrefaction stage, in which the tissues tend to become more flaccid, facilitating the disintegrating action of the fly larvae (Rosa et al. 2009). Furthermore, the difference in the duration of the black putrefaction stage between both periods could have happened because more specimens visited the carcasses for a longer period of time in the putrefaction stage during the rainy season, which lasted 2 d, than during the dry season. There could possibly have been a greater number of larvae, which accelerated decomposition and reduced the time of the black putrefaction stage (Recinos-Aguilar et al. 2019).

The longer exposure periods of the above-mentioned carcass stages were reflected in the composition, species richness, and abundance of individuals, which were longer in the black putrefaction and butyric fermentation stages. The black putrefaction stage was distinguished by the existence of holes throughout the carcasses' bodies, as well as swelling and volume reduction, and a strong odor. The butyric fermentation stage was characterized by wrinkling, the presence of mold in the carcasses' bellies, extremities of the bodies, such as the head and feet, with exposed bones, and the characteristics described by Bornemissza (1957), which were also observed by Rosa et al. (2009) and Lopes et al. (2018) in studies conducted with swine carcasses in Cerrado areas in Minas Gerais, in Southeast Brazil, and Atlantic Forest in Bahia, in Northeast Brazil.

Five species were pioneers on the first day of exposure of the carcasses, both in the dry (*D. carvalhoi*, *O. avuncula*, *O. thornax*, *O. timida*, and *R. belforti*) and in the rainy season [*D. carvalhoi*, *O. avuncula*, *O. thornax*, *P. (E.) collusor*, and *P. (S.) lambens*]. With the exception of *O. avuncula*, these species were also present in all the other four stages of decomposition, mainly the intermediate ones. This was also observed by Barros et al. (2008) for *D. carvalhoi* and *O. thornax* in the Cerrado of Distrito Federal, Midwest region; and for *P. (E.) collusor* and *P. (S.) lambens* in the Cerrado of Minas Gerais, Southeast region by Pesato et al. (2019). Other species were significant because they appeared in specific stages, such as putrefaction (for example, *H. neuzalmeidae* in the dry season, and *D. pusilla* and *O. simplicoides* in the rainy season), or black putrefaction [for example, *P. (E.) anguilla* and *P. (P.) chrysostoma* in the dry season, and *O. intona* in the rainy season], or butyric fermentation [for example, *O. bakeri*, in the dry season, and *B. (A.) denieri*, *D. paulistana*, *O. xanthosoma* and *T. (C.) larvicida*, in the rainy season]. Species groups that visit certain stages of carcass decomposition are vital for understanding the succession process and, as a result, making inferences about the post-mortem interval period (Oliveira-Costa 2011, Vairo and Moura 2021).

The information presented in the current study on the species of sarcophagids collected in the stages of decomposition of swine carcasses in the Cerrado of the country's Northeast region is very important for forensic entomology, as it can help to elucidate cases of displacement and estimation of the post-mortem range of corpses, of equivalent body mass, in similar environmental conditions, based on the predicted time of occurrence of the species.

In the two assessed periods, the composition and richness of species, as well as the abundance of individuals, differed in the stages of decomposition of the carcasses, with some species present in specific stages and periods. The list of species presented here, along with the discovery of new ones for science belonging to the genus *Helicobia* [further details on the description and habits of this species can be found in the work by Silva et al. (2022)], and new records and abundance values for the Cerrado, Northeast region, and the state of Maranhão, contribute to closing the knowledge gaps regarding Linean, Wallacean, and Prestonian deficits on sarcophagid species. The first deficit, Linnean, refers to a lack of information on which sarcophagid species are found in a specific locality or region. The Wallacean gap relates to holes in knowledge concerning the distribution of sarcophagid species. The third deficit, Prestonian, focuses on information gaps on the abundance patterns of Sarcophagidae species and their regional and temporal fluctuations, such as those identified in the current study's swine carcass stages (Cardoso et al. 2011, Hortal et al. 2015).

Acknowledgments

We are grateful to Dr. Francisco Limeira-de-Oliveira (UEMA), for invaluable infrastructure and support to develop this project in the Universidade Estadual do Maranhão; and to the colleagues who helped in the field and/or laboratory activities: Eduardo A. Silva, Neuza de A. Silva, José R. P. Silva Júnior, Liliane T. Neves, Geniana A. Reis, Elisvaldo V. dos Santos, Alberico A. Santos, Lazaro C. M. França, Joselma P. de Góis, Cassio L. A. da Silva, Laiana M. de Oliveira, Gizélia A. Cunha, Mariana M. Abreu, Erisvane M. da Silva, Erisleide M. da Silva, Luciana da S. Santos, Irlice G. de G. Santos, Aldiléia L. Costa, Rafael A. de Paula, Deyse W. A. Marques, Rosa C. R. da Silva, Deusiano C. de Almeida, and Josué de J. Sousa. We also thank Paulo R. C. dos Santos for making the map and SEMUMA (Secretaria Municipal de Meio Ambiente e Preservação dos Recursos Naturais de Caxias, MA) for authorizing this study in the Área de Proteção Ambiental Municipal do Inhamum. The first author thanks FAPEMA (Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão) for the doctoral research grant (Process BD-02769/20). We also thank Dr. Cátia Antunes de Mello-Patiu (*In memoriam*) for her suggestions made to the project that originated this article and for the various taxonomic and forensic studies about sarcophagids that she published throughout her scientific career, which supported several other works in South America, mainly in Brazil.

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