Papéis Avulsos de Zoologia
Museu de Zoologia da Universidade de São Paulo

ARTICLE

The Chrysidoidea Wasps (Hymenoptera, Aculeata) in Conventional Coffee Crops and Agroforestry Systems in Southeastern Brazil

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Abstract. Agroforestry systems represent the integration of agricultural crops with native vegetation. These systems are of great importance to minimize the agricultural impact in the land through intercropping of these vegetations. Despite of the importance of Chrysidoidea as parasitoids wasps associated with different groups of insects, there is no study comparing the assemblages of these hymenopterans in conventional and agroforestry systems in southeastern Brazil. The "Pontal do Paranapanema", located in the extreme west of the state of São Paulo (Brazil), has historically been occupied by coffee crops and some small areas of agroforestry systems. Therefore, this study aimed to verify the abundance and composition of Chrysidoidea wasp fauna in different conventional coffee crops and agroforestry systems located in this region. To do so, we collected in six different localities in the "Pontal do Paranapanema" using a Malaise trap in each locality, with collections occurring monthly between June 2011 and July 2012. A total of 3,623 Chrysidoidea specimens of three families were collected: Bethylidae, with four genera and 3,396 individuals, representing 93.73% of the total collected; Chrysididae with 11 genera and 151 individuals (4.16%), and Dryinidae with five genera and 76 individuals (2.09%). In terms of abundance, the agroforestry was responsible for most of the individuals collected (n = 2029), followed by the conventional systems with 1,406 individuals and the transitional with 188. The most abundant genera were *Epyris* and *Dissomphalus,* responsible for about 92% of the total of Chrysidoidea collected. Most of the genera of Chrysididae were collected in the conventional systems alone or in both conventional and agroforestry systems. For Bethylidae and Dryinidae, no genera were found exclusively in the conventional system. It is expected that the structural complexity of each one of the different ecosystems impact directly in the fauna of Chrysidoidea parasitoids associated.

Key-Words. Bethylidae; Chrysididae; Dryinidae; Malaise trap; Parasitoids.

INTRODUCTION

Degradation, fragmentation and destruction of habitats play central roles among the pressures driving biodiversity loss (Rands *et al.,* 2010; Haddad *et al.,* 2015). The conversion of native vegetation to agricultural systems has been the most important disturbance of natural ecosystems caused by human activities (Pereira *et al.,* 2010; Foley *et al.,* 2011). With continued population growth, agricultural demand is necessary to guarantee future food security (Foley *et al.,* 2011).

Coffee is considered the most important commodity in the world after oil. Besides that, Brazil is the most important country that produces and exports coffee worldwide (Fernandes *et al.,* 2012; Volsi *et al.,* 2019; Macedo *et al.,* 2020). The conventional coffee farming has adopted increasingly intensive management in agrochemicals. This style of coffee farming has as its main characteristics the simplification of agroecosystems (monoculture), with periodic use of pesticides and synthetic fertilizers, causing negative environmental, ecological, health and social consequences and implications (Lopes *et al.,* 2012).

Preservation of native vegetation into land use systems, such as in agroforestry, is an interesting sustainable alternative in this scenario (Steffan-Dewenter *et al.,* 2007; McGinty *et al.,* 2008; Negawo & Beyene, 2017). In addition to maintain-

Pap. Avulsos Zool., 2020; v.60: e20206058
http://doi.org/10.11606/1807-0205/2020.60.58
http://www.revistas.usp.br/paz
http://www.scielo.br/paz
Edited by: Helena Carolina Onody
Received: 15/07/2020
Accepted: 13/10/2020
Published: 16/11/2020

ISSN On-Line: 1807-0205
ISSN Printed: 0031-1049
ISNI: 0000-0004-0384-1825

ing the balance of biodiversity through the association of different cultures, allowing the existence of different pest control agents, agroforestry systems were created primarily to optimize land use, reconciling forest production with food production, conserve soil and reduce land pressure caused by agricultural production. (Engel, 1999; Meirelles, 2003).

Agroforestry systems are productive systems with greater biological complexity (consortia and polycultures) composed by the integration of diversified species of trees and shrubs with agricultural crops and tend to be more efficient, sustainable, resilient and productive (Meirelles, 2003; Altieri, 2012; Paludo & Costabeber, 2012; Lopes *et al.,* 2014; Martínez-Salinas, 2016). In complex and diversified agroforestry there are great difficulties to manage the system in a more sustainable way, due to the diversification of species that are little known. Simplified systems are easier in this regard, but most are unsustainable, allowing decreases or even losses in the abundance of organisms, in special to insects such as the parasitoids, which control populations of other insects that cause damage to the crops (Meirelles, 2003).

Hymenoptera, represented by ants, bees and wasps, is an important group of insects present in all terrestrial environments, including agroforestry systems (Hanson & Gauld, 2006). These insects play an important role in pest control and commercial production (Hanson & Gauld, 2006; Heraty *et al.,* 2011). Among Hymenoptera, the parasitoid wasps of the superfamily Chrysidoidea, composed by the living families Bethylidae, Chrysididae, Dryinidae, Embolemidae, Plumariidae, Sclerogibbidae and Scolebythidae (Brothers, 2006), are associated with different groups of hosts, like Embioptera, Lepidoptera, Coleoptera, Hemiptera, Hymenoptera and Phasmatodea (Azevedo & Helmer, 1999; Brothers, 2006; Fernández, 2006; Hanson & Gauld, 2006; Melo *et al.,* 2012; Guglielmino *et al.,* 2013; Martins & Domahovski, 2017a, b; Morales-Silva *et al.,* 2019; Martins *et al.,* 2020). The diversity of this superfamily is estimated at approximately 16,000 species, of which about 8,000 are described (Azevedo *et al.,* 2018; Olmi *et al.,* 2019; Pauli *et al.,* 2019; Chény *et al.,* 2020). Among the families of Chrysidoidea, three are considered the most diverse: Bethylidae with 96 genera and about 2,920 species, Chrysididae with 110 genera and about 3,000 species, and Dryinidae with 52 genera and 1,900 species (Azevedo *et al.,* 2018; Olmi *et al.,* 2019; Pauli *et al.,* 2019). The other Chrysidoidea families are less diverse, little known and rarely collected (Brothers, 2006; Melo *et al.,* 2012).

There are some studies investigating the Chrysidoidea fauna in southeastern Brazil, most of them related to faunistic fauna associated with the Atlantic Forest, especially in the states of Espírito Santo, Paraná and São Paulo (Azevedo & Helmer, 1999; Azevedo & Santos, 2000; Azevedo *et al.,* 2002, 2003, 2006, 2015; Alencar *et al.,* 2007). Others studies focused on the taxonomy of Dryinidae (Martins, 2015, 2018, 2019; Martins *et al.,* 2015a, b, 2020; Martins & Domahovski, 2017a, b). However, the literature about Chrysidoidea diversity in agroforestry systems is extremely scarce in this region of Brazil (Nakayama *et al.,* 2008). Therefore, this study aimed to verify and compare the occurrence and composition of Chrysidoidea fauna sampled in agroforestry and conventional coffee production systems located in southeastern Brazil.

Figure 1. Map showing the collection sites of Chrysidoidea wasps in the conventional, agroforestry and transitional systems in the "Pontal do Paranapanema" area, state of São Paulo, Brazil. The different colored squares represent: S.A. - Conv. (red); S.J.F. - Conv. (green); S.F.- SAF (yellow), S.J.M. - SAF (blue); S.S. - SAF (white); S.M.-Trans. (light blue).

Table 1. Collection sites of Chrysidoidea wasps of the "Pontal do Paranapanema" region, São Paulo, Brazil.

Name of the locality	Geographic coordinates	System	Description
"Sítio Antônio" – S.A. – Conv.	22°30′12″S; 52°02′57″W	Conventional	Coffee monoculture system with application of agrochemicals (area of 3 hectares)
"Sítio José Fusca" – S.J.F. – Conv.	22°29′43″S; 52°22′03″W	Conventional	Coffee monoculture system with application of agrochemicals (area of 0,5 hectare)
"Sítio Francisco" – S.F. – SAF	22°27′59″S; 52°01′00″W	Agroforestry	Agroforestry system composed of 32 native tree species, some exotic fruit trees and coffee trees, managed agroecologically (without chemical inputs) (area of 1 hectare)
"Sítio João Moreno" – S.J.M. – SAF	22°29′40″S; 52°22′56″W	Agroforestry	Agroforestry system composed of 18 tree species in consortium with coffee trees and agroecological management (area of 1 hectare)
"Sítio Santiago" – S.S. – SAF	22°29′50″S; 52°22′06″W	Agroforestry	Agroforestry system composed of 14 tree species intercropped with coffee trees, with agroecological management (area of 1 hectare)
"Sítio Manoel" – S.M. – Trans.	22°28′08″S; 52°23′29″W	Transitional	Coffee monoculture system, with hedge formed by native tree species around the stands, received chemical fertilizers and was free of pesticide use (area of 2 hectares)

MATERIAL AND METHODS

Study area

This study was carried out in an area named "Pontal do Paranapanema" (Fig. 1), a region historically occupied by large farms based on monoculture and ranching, and recently by the cultivation of sugarcane (*Saccharum* sp.) and coffee plantations (*Coffea arabica* L.). This region is also considered the second poorest region of São Paulo (Brazil), basing its economy mainly on the agricultural exploration and the cultivation of sugarcane (Silva *et al.,* 2006; Lopes *et al.,* 2014).

The areas selected for collection of the Hymenoptera parasitoids were agroforestry systems associated with coffee and fruits, and conventional coffee crops at "Fazenda Ribeirão Bonito" (Fig. 1, Table 1), a rural settlement area located near the Morro do Diabo State Park, belonging to the municipality of Teodoro Sampaio, São Paulo, Brazil. One of the collection sites – "Sítio Manoel – S.M.-Trans – was classified as a transitional system. The collections were performed monthly using one Malaise trap model Townes (1972) (Fig. 2) in each of the six localities.

Sampling of Chrysidoidea

Malaise traps were installed in the central part of the evaluated systems, with one trap per system. The collections were made every 30 days for a period of 13 months, from June 2011 to July 2012. Every 15 days inspections were carried out on the traps to check for damage and, if necessary, repair or replace them. The Hymenoptera were separated from other insect orders and the Chrysidoidea were identified to genus level using keys proposed by Kimsey (2006), Olmi & Virla (2014) and Vargas-Rojas & Terayama (2006). The Chrysididae were sent to Dr. Daercio Lucena, mounted and deposited in the Coleção Entomológica "Prof. João Camargo" of Faculdade de Filosofia, Ciências e Letras de Ribeirão Preto, Ribeirão Preto, São Paulo, Brazil (RPSP; curator Dr. E.A.B. Almeida). Bethylidae and Dryinidae were preserved in 70% ethanol and deposited in the Coleção de Hymenoptera Parasitoides of Universidade Federal de São Carlos, São Carlos, São Paulo, (DCBU; curator Dr. A.M. Penteado-Dias).

Figure 2. Malaise trap (Townes model) installed in the conventional system (S.J.F. – Conv.), in the "Pontal do Paranapanema" region, São Paulo, Brazil.

RESULTS AND DISCUSSION

A total of 3,623 specimens of Chrysidoidea belonging to three families were collected: Bethylidae with four genera and 3,396 individuals, representing 93.73% of the total collected; Chrysididae with 11 genera and 151 individuals (4.16%) and Dryinidae with five genera and 76 individuals (2.09%) (Table 2).

Of the 20 Chrysidoidea genera collected, two were restricted to the conventional systems, all of them belonging to Chrysidinae; three genera were restricted to the agroforestry, one of each family, and no genera was collected exclusively in the transitional system. The conventional systems shared with the agroforestry three genera (one of Bethylidae and two of Dryinidae), and three other genera with the transitional systems, all of them belonging to Chrysididae. The agroforestry shared with the transitional system two genera, one of Bethylidae and one of Dryinidae. Seven genera were found in the three types of systems, one of Bethylidae, one of Dryinidae, and five of Chrysididae (Fig. 3). In terms of abundance, the agroforestry systems were responsible for most of the individuals collected (n = 2029), followed by the conventional systems with 1,406 individuals and the transitional with 188. Approximately 92% of this amount is because of the bethylid genera *Epyris* and *Dissomphalus* (Table 2).

Bethylidae was the most abundant Chrysidoidea family sampled in several other studies of Hymenoptera

Table 2. Abundance of the Chrysidoidea genera in the "Pontal do Paranapanema" region, São Paulo, Brazil.

Family / Subfamily / Genera	S.A. – Conv.	S.J.F. – Conv.	S.F. – SAF	S.J.M. – SAF	S.S. – SAF	S.M. – Trans.
Bethylidae						
Bethylinae						
Goniozus Förster	0	3	6	5	0	0
Epyrinae						
Epyris Westwood	550	739	438	221	417	129
Bakeriella Kieffer	0	0	1	6	12	29
Pristocerinae						
Dissomphalus Ashmead	0	0	0	35	805	0
Chrysididae						
Chrysidinae						
Caenochrysis Kimsey & Bohart	4	9	8	2	3	5
Chrysis Linnaeus	11	6	6	2	8	1
Elampus Spinola	10	3	0	0	2	1
Exallopyga French	0	0	2	0	0	0
Hedychrum Latreille	1	0	0	0	0	0
Holophris Mocsáry	0	1	0	0	0	2
Holopyga Dahlbom	2	7	0	0	0	15
Ipsiura Linsenmaier	3	2	12	1	1	2
Muesebeckidium Krombein	0	2	0	0	0	0
Neochrysis Lisenmeyer	2	1	0	0	0	1
Pleurochrysis Bohart	2	4	0	1	5	1
Dryinidae						
Anteoninae						
Anteon Jurine	0	0	0	0	1	1
Deinodryinus Perkins	0	0	0	0	5	0
Aphelopinae						
Aphelopus Dalman	0	2	0	0	1	0
Dryininae						
Dryinus Latreille	1	1	5	4	2	1
Gonatopodinae						
Gonatopus Ljungh	2	38	4	5	3	0
Total	588	818	482	282	1265	188

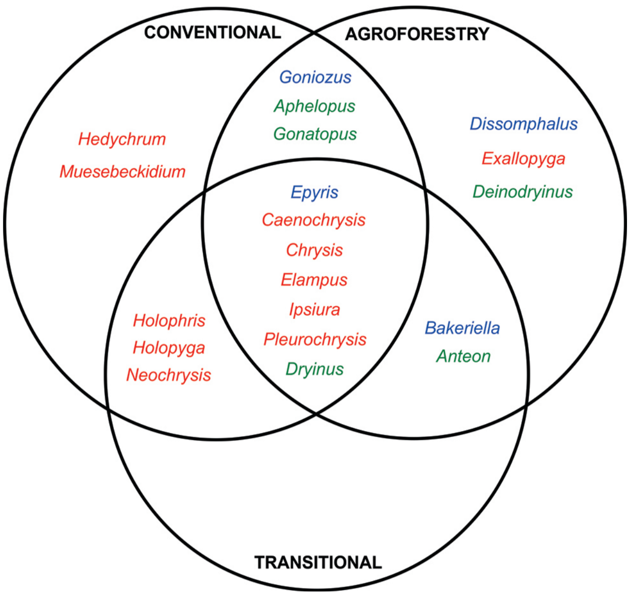

Figure 3. Venn diagram showing exclusive and shared genera of Chrysidoidea among conventional, agroforestry and transitional systems in the "Pontal do Paranapanema" region, São Paulo, Brazil. Bethylidae in blue, Chrysididae in red and Dryinidae in green color.

parasitoids in Brazil, both in natural systems (Azevedo *et al.,* 2002, 2003; Alencar *et al.,* 2007) and in agricultural systems, including coffee crops and agroforestry (Perioto *et al.,* 2004; Sperber *et al.,* 2004; Ferreira *et al.,* 2013; Lara *et al.,* 2015). In our study, this family was more abundant in the agroforestry system, and three of the four genera occurred both in agroforestry and conventional systems (Fig. 3). These hymenopterans are ectoparasitoids of Lepidoptera and, mainly, Coleoptera that live in cryptic habitats (Evans, 1964; Azevedo & Hermes, 1999; Azevedo *et al.,* 2010, 2018; Morales-Silva *et al.,* 2019). In agroforestry systems, the presence of different species of trees contribute to increasing the leaf litter stratum, which would consequently contribute to the cryptic habitat of the Bethylidae hosts.

Epyris Westwood was the most abundant genus of Bethylidae, collected in all the environments, representing approximately 69% of all individuals collected in the three systems (Fig. 3, Table 2). This genus presents several predator species of soil-dwelling beetle, like Tenebrionidae (Evans, 1964). The second genus with higher abundance was *Dissomphalus* Ashmead, representing approximately 23% of the total specimens collected, and found exclusively in the agroforestry system. Azevedo (2003) suggested that *Dissomphalus* is one of the most common genera of Bethylidae in the Neotropical Region, especially in rain forests. According to Evans (1964), *Dissomphalus* probably attacks small beetles, including certain myrmecophiles. The genus *Bakeriella* Kieffer occurred in both agroforestry and transitional systems. Their hosts are unknown (Azevedo, 2014). The genus *Goniozus* Förster occurred in the conventional and agroforestry systems (Fig. 3). This genus is associated to ectoparasitoids of microplepidopteran larvae (Morales-Silva *et al.,* 2019). These last two genera were not very abundant in relation to the others bethylids collected, representing 1,7% of the total collected individuals (Table 2).

In Bethylidae, *Cephalonomia stephanoderis* Betrem and *Prorops nasuta* Waterston represent two of the most efficient parasitoids in the biological control of *Hypothenemus hampei* Ferrari (Coleoptera, Scolytidae), the most important coffee pest (Infante *et al.,* 2001; Pérez-Lachaud *et al.,* 2002). These parasitoids were introduced in coffee growing areas in Brazil in the 1990s to reduce the damage caused by *H. hampei* (Infante *et al.,* 2005; de Souza *et al.,* 2006). None of these Bethylidae genera were recorded.

Chrysididae, in our study represented only by the subfamily Chrysidinae, differently than Bethylidae, was more abundant in the conventional systems, where also there were five exclusive genera (Fig. 3). Chrysidinae are parasitoids of solitary aculeate hymenopterans, such as Sphecidae, Apidae, Megachilidae, Halictidae and Vespidae. Little is known about host-parasite relationships of the neotropical Chrysididae (Kimsey, 2006; Pärn *et al.,* 2015).

Dryinidae was represented by four subfamilies and five genera: Aphelopinae (*Aphelopus* Dalman), Anteoninae (*Anteon* Jurine and *Deinodryinus* Perkins), Dryininae (*Dryinus* Latreille) and Gonatopodinae (*Gonatopus* Ljungh). This family was a little more abundant in the conventional systems (Table 2), although no genus was found restrictively in the coffee monocultures. *Dryinus* was the only genus collected in the three types of ecosystems, while *Deinodryinus* was collected only in the agroforestry system (Fig. 3). These wasps are parasitoids and predators of Auchenorrhyncha (Hemiptera), and as many of the host species are considered pests in agriculture, the Dryinidae are considered beneficial insects (Guglielmino *et al.,* 2013; Martins *et al.,* 2020). There are some studies about records, descriptions of new species and associated hosts of Dryinidae fauna in different habits in Brazil, including Atlantic forest, Amazon forest and Cerrado savanna, but none of them focus on agroforestry systems (Martins, 2015, 2018, 2019; Martins & Krinski, 2016; Martins & Domahovski, 2017a, b; Versuti *et al.,* 2014; Martins *et al.,* 2015a, b, 2020).

Host-parasitoid-plant interactions are highly impacted by environmental structure and complexity. The movement of herbivores, their length of stay, abundance and mortality are directed associated with the structure of the vegetation. These factors, in turn, are important for the occurrence, prevalence and diversity of the associated parasitoid fauna (Obermaier *et al.,* 2008). Azevedo (2003) indicates the preference of *Dissomphalus* in humid regions or with denser vegetation cover, which the agroforestry systems can better provide in relation to the coffee systems, for example. On the other side, some studies indicate the preference of some solitary wasps and bee species in more open areas, probably because these habitats can create favorable conditions for the location of prey and there are more nests sites available for ground nested species (Klein *et al.,* 2002; Buschini & Woiski, 2008; McCravy *et al.,* 2009). Also, there are some studies demonstrating the importance of the pollination performed by wild and managed bees in *Coffea arabica* (see Macedo *et al.,* 2020). As the Chrysidinae are parasitoids of the solitary aculeate hymenopterans, the high number of genera found in the conventional system alone or in both conventional and agroforestry is probably related to their hosts available in such systems.

According to Jose (2012), agroforestry plays certain roles in conserving biodiversity, such as providing habitat for species that can tolerate disturbance levels, providing ecological corridors between habitat remnants, and protecting ecosystems services as erosion control and water recharge. Because of the structural complexity of agroforestry systems, some studies demonstrate that they can maintain a high conservation potential, sometimes with even higher species richness levels of certain taxonomic groups when compared with native systems (Schulze *et al.,* 2004; Pineda *et al.,* 2005; Lima *et al.,* 2014).

All the Chrysidoidea families registered in this study are poorly known in the Neotropical Region. In fact, there are no identification keys or taxonomical revisions for most of the genera of these families. Although we did not identify the individuals to the specific level, we believe this study is extremely important since it is one of the fewest to investigate such patterns with the Chrysidoidea in the southeastern region of Brazil. Furthermore, we strongly encourage taxonomic studies involving these taxa, so that the gaps related to their biology begin to be better explored.

AUTHOR'S CONTRIBUTION

PRL collected the specimens; ALM: identified the specimens. All authors wrote, reviewed, edited the manuscript and approved its final version.

ACKNOWLEDGEMENTS

Many thanks to Instituto Nacional de Ciência e Tecnologia dos Hymenoptera Parasitoides da Região Sudeste Brasileira (INCT – Hympar/Sudeste – CNPq/FAPESP/CAPES) for financial support. A special thanks to Dr. Daercio Lucena for the identification of the Chrysididae. Many thanks to CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) for fellowship provided to ALM (grant #151827/2019-2), CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) for fellowship provided to JRAL (grant #88882.382399/2019-01) and FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) for fellowship provided to PRL (grant #2010/07119-5). Many thanks to the anonymous reviewers for their critical reading and helpful comments.

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Published with the financial support of the "Programa de Apoio às Publicações Científicas Periódicas da USP"