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Solitary wasps diversity (Hymenoptera: Aculeata) in different cultivation environments

Diversidade de vespas solitárias (Hymenoptera: Aculeata) em diferentes ambientes de cultivo

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RESUMO: As vespas contribuem para a qualidade ambiental e os serviços ecossistêmicos e desempenham um papel fundamental no funcionamento de muitos ambientes. O presente estudo investigou a diversidade de espécies de vespas solitárias que ocuparam ninhos-armadilha em ambientes de cultivo, bem como a arquitetura dos ninhos encontrados. O estudo concentrou-se em três áreas de agroecossistema, onde foram instalados 30 blocos de ninhos-armadilha, com quatro diâmetros (5 mm, 7 mm, 9 mm e 11 mm). Um total de 56 ninhos foram ocupados por vespas solitárias, sendo as espécies mais freqüentes *Trypoxylon* sp.1, Crabronidae (N=100, 54,9%), *Pachodynerus* cf. *Brevithorax*, Vespidae (N=31, 17,0%), *Trypoxylon* sp.2, Crabronidae (N=27, 14,8%) e *Caenochrysis nigropolita*, Chrysididae (N=9, 4,9%). As vespas ocuparam preferencialmente os ninhos-armadilha de 5 mm e 7 mm de diâmetro. Seis famílias de vespas foram registradas, sendo as mais abundantes Crabronidae com 127 indivíduos, seguida da família Vespidae (N=36). O número reduzido de espécies registradas na área de estudo pode estar relacionado ao uso frequente de pesticidas e às práticas agrícolas, que podem danificar os locais de nidificação. Esses resultados fornecem alertas importantes para o uso de práticas agrícolas e enfatizam a necessidade de adoção de estratégias eficazes para a conservação e manejo sustentável das populações desses insetos potencialmente benéficos.
PALAVRAS-CHAVE: Conservação, himenópteros, agroecossistemas.

ABSTRACT: Wasps contribute to environmental quality and ecosystem services, and play a key role in the functioning of many environments. The present study identified the diversity of species of solitary wasps that occupied trap-nests in farming environments. as well as the architecture of the nests found. The study focused on three areas of agroecosystem, where 30 blocks of trap-nests, with four diameters (5 mm, 7 mm, 9 mm, and 11 mm), were installed. A total of 56 nests were occupied by solitary wasps, with the most frequent species being *Trypoxylon* sp.1 (N=100, 54.9%), *Pachodynerus* cf. *brevithorax* (N=31, 17.0%), *Trypoxylon* sp.2 (N=27, 14.8%) and *Caenochrysis nigropolita* (N=9, 4.9%). The wasps occupied preferentially the trap-nests of 5 mm and 7 mm in diameter. Six wasp families were recorded, with the most abundant being the Crabronidae with 127 individuals, followed by the family Vespidae (N=36). Reduced number of species was recorded in the study area with frequent use of pesticides, and farming practices, which may damage nesting sites. These findings provide important guidelines for the use of agricultural practices, and emphasize the need for the adoption of effective strategies for the conservation and sustainable management of the populations of these potentially beneficial insects.
KEYWORDS: Conservation, hymenopterans, agroecosystems.

INTRODUÇÃO

Studies in agroecosystems structures are of considerable interest with regard to their potential contribution for the maintenance of local biodiversity (PERFECTO; VANDERMEER, 2008) and the creation of microclimatic gradients within the landscape (TYLIANAKIS et al., 2005). A wide variety of arthropods are associated with agroecosystems, and it will be essential to understand their relationships with these systems, in order to develop effective management practices to guarantee the sustainability of the agricultural practices and the maintenance of local biodiversity (MATOS et al., 2013).

Among the high diversity founded in insects found in agroecosystems, the solitary wasps (Hymenoptera), are important for the maintenance of natural environments, given that they can potentially provide fundamental ecosystem services, such as biological control, for agricultural systems (BROTHERS, 2006a). These insects are considered to be sensitive to environmental alterations, and are widely employed as bioindicators of environmental quality in both natural ecosystems and different types of land use (AGUIAR; MARTINS, 2002; TYLIANAKIS et al., 2005; LOYOLA; MARTINS, 2006; MATOS et al., 2013, 2016). Solitary wasps and bees vary considerably in their foraging behavior, nest design, and oviposition patterns (ASSIS; CAMILLO, 1997; GARÓFALO et al., 2004; SANTONI; DEL LAMA, 2007; PIRES et al., 2012), and these wasps are considered to be the natural enemies of an enormous variety of arthropods (KLEIN et al., 2004; BUSCHINI; WOISKI, 2008; BUSCHINI; BUSS, 2010). Factors as diversity of floral resources, land-use, microclimate in regard to air humidity and local temperature may have an influence on the behavior of the solitary wasps (MATOS et al., 2013; STRANGLER et al., 2015). Local of nesting is one behavior influenced by habitat fragmentation (MORATO; CAMPOS, 2000; STRANGLER et al., 2015) and these locals are diverse in solitary waps. In the universe of more than 34,000 species of aculeate wasp described (MORATO et al., 2008), 90% of these species are solitary, with nesting behavior on the ground (BUYS, 2012) or in preexisting cavities found in hollow tree trunks and branches or in holes made by other insects, where they construct their brood cells from mud or resin (GARÓFALO et al., 2004).

The habit of these wasps of nesting in preexisting cavities facilitates research, given that the female wasps can be easily attracted to manmade tubular structures, known as trap-nests (AGUIAR; MARTINS, 2002). This capture method is widely-used, and it provides reliable data on the interactions between wasp populations and the environment, their parasitizing behavior, nesting preferences, the materials used to build the nests, life cycle (AGUIAR; MARTINS, 2002; BUSCHINI et al., 2006; GARÓFALO et al., 2004; NEVES et al., 2012; COSTA; BUSCHINI, 2016), internal architecture of the nests, and the structure of the cocoon (ASSIS; CAMILLO, 1997;

CAMILLO; BRESCOVIT, 2000; SANTONI; DEL LAMA, 2007; RIBEIRO; GARÓFALO, 2010; OLIVEIRA; GONÇALVES, 2017).

In regards to the solitary wasps, the principal families are Vespidae (Eumeninae), Pompilidae, Chrysididae, Sphecidae, and Crabronidae. These wasps build their nests in hollow stems or branches, and in holes made by *xylophagous* beetles (MORATO; CAMPOS, 2000), which they provision with spiders and/or phytophagous insects on which the larvae feed (BATISTA, 2010). These wasps may also parasitize solitary bees (MACHADO, 2011), and a wide range of other arthropods, including insects of the orders Thysanoptera, Heteroptera, Psocoptera, Orthoptera, Blattaria, Lepidoptera, Diptera, Coleoptera, and Hymenoptera, and some families of the orders Araneae and Collembola (TRAD; SILVESTRE, 2017).

To allow sustainable food production maintaining the ecosystems services provided, it is important to evaluated how the important roles played by solitary wasps in different terrestrial ecosystems are influenced by agronomics practices. Nesting studies provided a basic tool for the investigation of the diversity of solitary wasps, including the variation among environments, and the response of the species to natural or anthropogenic impacts. Data on the ecological diversity of solitary wasps are important, not only for the management of the wasp populations themselves, but also for the planning of adequate conservation strategies for natural and agricultural ecosystems. Considering the importance of solitary wasps and their biological potential we addressed the following questions to contribute to agricultural systems: (1) is population abundance of solitary wasps change according to the diversity existing in the landscape? (2) Is the nesting influenced by the land-use? and (3) What is diameter trap-nests preferred by the solitary wasps founded in different habitats?

METHODOLOGICAL PROCEDURE
STUDY AREA

The present study focused on an agroecosystem located in the Agreste region of Pernambuco, Brazil (9°01'02"S, 36°30'16"W, altitude 850 m a.s.l.). Three sampling areas were selected, representing different types of crop. Area I (monoculture): coffee (*Coffea arabica* Linnaeu) plantations; Area II (differents species of the same generus): orchard of citrus fruits (*Citrus* spp. Linnaeu) fruits; Area III: (mixed orchard) brazilian cherry (*Eugenia uniflora* Linnaeu), avocado (*Persea americana* Mill.), brazilian grape tree fruit (*Plinia cauliflora* (Mart.) Kausel), macadamia nut (*Macadamia integrifolia* Maiden & Betche), lychee (*Litchi chinensis* Sonn.), starfruit (*Averrhoa carambola* Linnaeu), sapodilla (*Manilkara zapota* Linnaeu), cashew (*Anacardiaceae occidentale* Linnaeu), red mombin (*Spondias purpurea* Linnaeu), custard apple (*Annona muricata* Linnaeu), atemoya (*Annona atemoya* Mabb.), and passion-fruit (*Passiflora edulis* Sims).

SAMPLING OF NESTS

For the comparative study of solitary wasps nesting, we chose three contiguous areas with different vegetal composition. We made 30 styrofoam blocks and fixed them in wooden frames. The block was fixed 1.5 m above the ground, in the three areas at 200–500 m from one another. Each block was lined with a box of type "panama" paper containing 36 trap-nests made of wood-colored Kraft paper (15 cm long), with nine nests of each of four different diameters (5 mm, 7 mm, 9 mm, and 11 mm), as in the study of Neves et al. (2012). The traps were randomly distributed in the three study areas in proportion to their size, with ten blocks (360 trap-nests) being placed in area I, which had an area of approximately two hectares, eight blocks (288 trap-nests) in area II (less than one hectare), and 12 blocks (432 trap-nests) in area III, which was over two hectares.

The traps were checked for nesting wasps every fortnight between February 2014 and February 2015. At the moment of the evaluation of the nests occupation, each occupied nest-trap was removed for analysis and replaced with a new nest-trap of the same diameter. The collected traps were inserted in 20 cm long PVC tubes, sealed with mesh, and taken to the Laboratory of entomology, where they were maintained under controlled conditions, at a temperature of 25 ± 1 °C, relative humidity of 75% ± 5%, and a 12 h/12 h night/day photoperiod, and monitored until the emergence of the wasps according to Neves et al. (2012). The adults were processed, quantified, and labelled. Replicate specimens were registered and sent to taxonomic specialists for the confirmation of the species identification.

DATA ANALYSIS

The trap occupation rate (%) was calculated by dividing the number of nests occupied by wasps by area by the total number of trap-nests of a given diameter, multiplied by 100. The relative frequency (RF%) of emerged individuals was calculated using methodology of Silveira-Neto et al. (1976). According to the formula: RF= (ni/N) x 100, being RF= relative frequency of the number of individuals in the sample area; ni = number of individuals from each sample area; N= total number of individuals in the sampled areas. Potential differences in these parameters (occupation rate and relative frequency of emerged individuals) among the three sampling areas were tested using Chi-square (χ^2). All these analyses were run in BioEstat 5.0 (AYRES et al., 2007).

Wasp species diversity was analyzed using the diversity indices of Margalef (α) and Shannon-Wiener (H'), and Pielou's evenness, J' (MAGURRAN, 2004). The Shannon-Wiener index was used to verify the degree of heterogeneity of the species diversity, based on the relative abundance of the solitary wasp species sampled. These indices were calculated in PAST 3.17 (HAMMER et al., 2001).

The seasonal variation in the nesting patterns of the solitary wasps was evaluated by the number of nests occupied each month during the study period, which was compared among study areas. The relationship between the relative frequency of nesting and climatic variables (precipitation (mm), temperature (°C), and relative humidity (%) was evaluated by a Spearman correlation analysis. The meteorological data were provided by the Pernambuco State Agronomy Institute (IPA, 2016).

RESULTS AND DISCUSSION

The present study investigate solitary wasps using trap-nests in agricultural systems of the Agreste region of the Brazilian state of Pernambuco. The samples collected during the study provided a large amount of data on the diversity of the wasps of the families Chrysididae, Crabronidae, Ichneumonidae, Sphecidae and Vespidae in the agroecosystem surveyed. Overall, 56 of the 1080 trap-nests installed in the study area were occupied by solitary wasps (Table 1), with the majority of these occupied traps (39) being found in area III (mixed orchard), with an occupation rate of 9.02%, followed by area II (citrus orchard), with 10 traps (occupation rate of 3.47%), and area I (coffee plantation), with only seven traps occupied, at a rate of 1.94%, While relatively low occupation rates were recorded in the present study, there did appear to be a systematic relationship with the diversity of the agroecosystem, given that the mixed orchard returned by far the highest rate (9.02%) of nest occupation (Table 1). There was, in fact, a highly significant difference ($\chi 2= 20.01$, d.f. = 2, $p < 0.0001$) among the areas, which indicates that the more diverse agroecosystem favored the abundance of solitary wasps.

Low trap occupation rate, as we found in this work, is often frequent. The importance of the ecosystem service provided by solitary wasps, have no direct relation with abundance founded in the agroecosytem. Santos (2011) recorded a low trap occupation rate, of approximately 8%, in sugarcane plantations and polyculture systems in Pernambuco, Loyola and Martins (2006) also recorded low occupation rates, of 2–3%, in solitary wasps in areas of monoculture and habitat management in Belo Horizonte, Minas Gerais (Brazil) and Matos et al. (2013) concluded that occupation rates may be affected by habitat management. Souza (2011) observed a similar pattern in a trap-nest survey of solitary wasps in agroecosystems and fragments of Atlantic Forest in central Bahia, where few nests were established in polyculture systems. Nest occupation then, is influenced by land use and local resources (KLEIN et al., 2002).

Although, we can not link nest occupation rates with importance of the specie in the local, our research indicates that the more diverse agroecosystem favored the abundance of solitary wasps. In this context, there is growing interest in the potential of agroecosystems for the maintenance of the biodiversity of hymenopterans, such as solitary wasps (MATOS et al., 2013), which are sensitive to alterations in the environment, and are widely used as bioindicators of environmental quality in a number of different ecosystems (AGUIAR; MARTINS, 2002; LOYOLA; MARTINS, 2006). The number of nests appears be related to the diversity of the vegetation, which may be reflected in a more substantial resource base, in both agricultural systems or agroecosystems and also the availability of nest-building materials (RIBEIRO; GARÓFALO, 2010; SANTOS, 2011; MATOS et al., 2013; NASCIMENTO; GARÓFALO, 2014) and in natural ecosystems (MORATO; CAMPOS, 2000; AGUIAR; MARTINS, 2002; LOYOLA; MARTINS, 2006; SANTONI; DEL LAMA, 2007; PIRES et al., 2012, AUKO, 2015, COSTA; BUSCHINI, 2016).

Is observed in the table 1, eight different wasps species were recorded in the agroecosystem surveyed in the present study, including members of five families: Crabronidae – *Trypoxylon* Latreille, 1796 sp.1 (n=23 nests) and *Trypoxylon* Latreille, 1796 sp.2 (five nests), Chrysididae – *Caenochrysis nigropolita* Bischoff, 1910 (five nests), Ichneumonidae, unidentified species (one nest), Sphecidae –*Podium* sp. Fabricius, 1804 (eight nests), Vespidae – *Hypancistrocerus* sp. Saussure, 1853 (one nest), *Pachodynerus* cf. *serrulatus* Brèthes, 1906 (three nests), and *Pachodynerus* cf. *brevithorax* Saussure, 1853, with 10 nests.

The predominance of *Trypoxylon*, in our study reinforces the relative importance of this genus in agricultural systems. This genus is a member of the family Crabronidae, which is represented by 1640 species in the Neotropical region, of which, 545 have been recorded in Brazil (AMARANTE, 2002). Buschini and Woiski (2008) found that this family is predominant in many different types of ecosystem, with the highest relative frequency (84.3%) in the samples collected, reinforcing the findings of the present study. *Trypoxylon* was the most common wasp genus recorded in the present study, as found in surveys conducted in different brazilian regions (ASSIS; CAMILLO, 1997; MORATO; CAMPOS, 2000; VIANA et al., 2006; BUCHINI; WOISKI, 2008; MELO; ZANELLA, 2010; PIRES et al., 2012), reflecting the diversity of this genus and the extent of its geographic distribution, in both natural ecosystems and agroecosystems.

Diverse studies have demonstrated the influence of the diversity of the vegetation on the species richness of the solitary wasps and bees collected in trap-nests (NEVES et al., 2014; COSTA; BUSCHINI, 2016). That why we have to promote the conservation of plant diversity in agricultural systems to favours the maintenance of both bees and wasps as said by Yamamoto et al. (2010) and Nascimento (2013). Plant diversity is not only important because of the abundance of the foraging resources essential for the survival of the individual, but also because of the availability of nest-building materials (ASSIS; CAMILLO, 1997; RIBEIRO; GARÓFALO, 2010; MATOS et al., 2013). Even in presence of plant diversity, dominant specie can be found in the area. Vieira (2015), in his work, we observed that 54 of 81 emerged individuals belong to the genera *Trypoxylon* and *Pachodynerus.*

Table 1. Number of nests built by diameters used of solitary wasps species and the number of individuals emerging, in different cultivated environments, Agreste region of Pernambuco, Brazil, between February 2014 and February 2015. RF - Relative Frequency (%). Diversity and uniformity indices: H' = Shannon-Wiener diversity, S = species richness; J'= Evenness; α= Margalef's diversity.

Taxon	**N of nests by diameter (mm)**				**N of nests**	**N of individuals by area**			**RF (%)**
	5	**7**	**9**	**11**		**I**	**II**	**III**	
Chrysididae									
Caenochrysis nigropolita Bischoff, 1910	4	1	0	0	5	0	0	9	4.9
Crabronidae									
Trypoxylon sp.1 Latreille, 1796	18	5	0	0	23	2	17	81	54.9
Trypoxylon sp.2 Latreille, 1796	0	0	4	1	5	16	2	9	14.8
Ichneumonidae	0	1	0	0	1	0	2	0	1.1
Sphecidae									
Podium sp. Fabricius, 1804	8	0	0	0	8	2	2	4	4.4
Vespidae									
Hypancistrocerus sp. Saussure, 1853	1	0	0	0	1	0	1	0	0.5
Pachodynerus cf. *serrulatus* Brèthes, 1906	2	1	0	0	3	0	0	4	2.2
Pachodynerus cf. *brevithorax* Saussure, 1853	3	7	0	0	10	4	1	26	17.2
TOTAL	36	15	4	1	56	24	25	133	100
N of trap-nests/area						360	288	432	
N of nests occupied/area						7	10	39	
Occupation rate (%)						1.94	3.47	9.02	
H' Index						0.98	1.12	1.20	
α						0.94	1.02	1.55	
J' Index						0.60	0.62	0.77	

Legends: Area I: Coffee plantation (*Coffea arabica* L.); Area II: Citrus orchard (*Citrus* spp. L.); Area III: Mixed orchard (for composition, see text).

The most common species, *Trypoxylon* sp.1, preferred trap-nests with diameters of 5 mm (18 nests) and 7 mm, with five nests (Table 1), whereas *Trypoxylon* sp.2 nested in four traps of 9 mm in diameter, and once in a 11 mm diameter trap. In the case of the family Vespidae, *P.* cf. *serrulatus* nested in traps its diameters of 5 mm (two nests) and 7 mm (one nest), whereas the more common *P.*cf. *brevithorax* preferred traps of 7 mm (seven nests) over those of 5 mm (three nests), with a total of 10 nests. *Hypancistrocerus* (Vespidae) and *Podium* sp. (Sphecidae) preferred traps with a diameter of 5 mm, with one and eight nests, respectively. In the case of the family Chrysididae, *C. nigropolita* also preferred nesting in traps with a diameter of 5 mm (four nests), with one nest in a tube of 7 mm in diameter. The unidentified species of the family Ichneumonidae built one nest in a trap of 7 mm in diameter. No significant preference (G = 18.25, d.f. = 21, p = 0.633) was found, overall, for traps of any given diameter. The *Trypoxylon* species were responsible for building the largest number of nests (n = 28), followed by *P.* cf. *brevithorax*, with 10 nests.

Concerning the construction of nests by *Trypoxylon*, in Anchieta Island State Park, Nascimento and Garófalo (2014) observed *Trypoxylon* species building nests in traps with diameters of 4 mm, 5 mm, 7 mm, and 11 mm, similar to those occupied in the present study. In addition to these similarities in diameters, the architecture of the nests observed in the present study, and the materials used, such as clay and sand, were also similar to those reported previously, in both natural environments and agroecosystems (ASSIS; CAMILLO, 1997; RIBEIRO; GARÓFALO, 2010; SOUZA, 2011; MATOS et al., 2013; PIRES et al., 2012; NASCIMENTO; GARÓFALO, 2014; OLIVEIRA; GONÇALVES, 2017; TRAD; SILVESTRE, 2017). Similar findings were also obtained by Aguiar and Martins (2002), Melo and Zanella (2010), and Woiski (2009), who recorded a predominance of crabonids, vespids, and sphecids, and preferences for tubes with diameters of 5 mm, 7 mm, and 9 mm. The preference of smaller diameter orifices for nest building and provisioning may reflect behavioral strategies adopted to minimize energetic expenditure in relation to the morphological characteristics and body structure of each species, which presumably replicates the wasps' behavior in their natural environment. Furthermore, Trad and Silvestre (2017) found that most wasp species are correlated with a specific type of phytophysiognomy, and that the distribution and diversity of these wasps are determined by the heterogeneity of habitats, their spatial arrangement, the availability of resources, including nest-building materials, and land use. Aguiar and Martins (2002) concluded that the occupation of larger orifices would require the expenditure of more energy and material for the construction of the nest, with the preference for a given diameter reflecting the body size of the female wasp.

In the provision of prey within the nests, the *Trypoxylon* nests were provisioned with spiders, whereas those of *Pachodynerus* contained caterpillars (Lepidoptera). *Hypancistrocerus* sp. was observed provisioning its nests with insects of the orders Coleoptera and Lepidoptera. *Podium* species also have potential controller of a specific type of agricultural pest. Camillo and Brescovit (2000) and Santoni et al. (2009) also recorded spiders in *Trypoxylon* nests. In Brazil, a number of trap-nest studies (BUSCHINI; WOISKI, 2008; MATOS et al., 2013; NASCIMENTO; GARÓFALO, 2014; COSTA; BUSCHINI, 2016) have recorded an abundance of wasps of *Trypoxylon*, those of *Pachodynerus* with caterpillars (NASCIMENTO; GARÓFALO, 2014;) and many other genera of the subfamily Eumeninae, that prey on an enormous diversity of insect pests or spiders to provision their offspring (ROSA, 2015). Trad and Silvestre (2017) report that few published studies focus specifically on the potential role of these wasp species as bioindicators or natural controllers of specific types of agricultural pest.

While *Podium* sp. was among the least abundant species (4.4% of the individuals recorded), the species of this genus are generally considered to be cosmopolitan predators of insects that are agricultural pests, and are thus important regulators of the populations of both pests and other, potentially beneficial arthropods, such as spiders and collembolans (RIBEIRO; GARÓFALO, 2010). This reinforces the need for further research on the nesting biology of *Podium* sp., in particular with regard to the sustainable management of this species in environments associated with agricultural systems.

In the use of materials for building nests, *Trypoxylon* species built nests usingclay and sand, with internal divisions and the tube extremity being made of clay, interspersed with some empty spaces. *Pachodynerus* also used clay to separate the cells within its nests. It was possible to observed the structure of the cocoon in some genera. The cocoons of *Trypoxylon* are dark brown, cylindrical, brittle, and shiny, with rounded extremities. In *Pachodynerus*, the cocoons are made of a fine layer of shiny secretion, which is probably produced by the larvae themselves, and adheres to the internal walls of the brood cell. In Podium sp., the cocoons are fusiform, smooth, brittle, brown, and shiny, with one rounded extremity, and the other, pointed. All the other wasp species presented similar nest-building behavior, using clay or grains of sand to construct their nests, and provisioning individual cells. Similar nest architecture was recorded in previous trap-nest studies of *Trypoxylon* and *Pachodynerus* in cultivated environments (ASSIS; CAMILLO, 1997; CAMILLO; BRESCOVIT, 2000; SANTONI; DEL LAMA, 2007; RIBEIRO; GARÓFALO, 2010, MATOS et al., 2013; BUSCHINI; BUSS, 2010; NASCIMENTO, 2013). The characteristics of the wasp cocoons recorded in the present study are closely similar to those recorded in previous studies.

Species diversity (Shannon-Wiener index) was lowest in area I (H'= 0.98), highest in area III (H'=1.20), and intermediate (H'= 1.12) in area II (Table 1). Even so, diversity was highest in area III, and this was reconfirmed by Margalef's index, which was also much higher in area III (α = 1.55), in comparison with areas I (α = 0.94) and II (α = 1.02). The relatively small number of species recorded in the present study may be attributed to the intense agricultural practices observed in the study area, which may limit the availability of potential nesting sites and reduce resource abundance. Areas I (J'= 0.60) and II (J'= 0.62) were also relatively similar in their evenness, whereas the index for area III (J' = 0.77) was much higher.

The species diversity (Shannon-Wiener index) of the study, the values were lower than those recorded by Pires et al. (2012) for the wasp and bee fauna of the Unilavras Boqueirão Biological Reserve in Ingaí, in the Brazilian state of Minas Gerais, which ranged from H' = 1.36 for Cerrado savanna, to H' = 1.59 for gallery forest, and H' = 1.76 for the forest edge. It seems likely that natural environments with little anthropogenic interference provide a greater abundance of resources for nest building and provisioning. Matos et al. (2013) concluded that the species richness and population dynamics of solitary wasps in agricultural systems may be impacted by the homogeneity of habitats, intense weeding and grazing, and climatic factors. Pires et al. (*2012*) recorded much higher evenness scores for solitary wasps in environments such as gallery forest (J' =0.99), forest edge (J' = 0.80) and Cerrado savanna (J' = 0.76). According Trad and Silvestre (2017) the degree of conservation of an ecosystem has a direct influence on its wasp diversity, with species richness and occurrence being related directly to the heterogeneity of habitats and their spatial arrangement.

The low species diversity recorded in the present study may be at least partly related to the agricultural practices used in the region, such as monthly weeding and bush clearance, in addition to the intensive use of pesticides and herbicides. The constant weeding (GUERRA et al., 2012) and application of herbicides (FREITAS; PINHEIRO, 2010; PINHEIRO; FREITAS, 2010) reduce the availability of ruderal plants within the area and potential sites for the construction of nests. However, while farming simplifies the landscapeand, typically, reduces local biodiversity, it can also contribute to conservation and the sustainable management of biodiversity and the ecosystem services provided by certain species, such as the solitary wasps (TSCHARNTKE et al., 2005), when specific practices are applied to ensure the maintenance of the populations of these beneficial insects.

The number of nests founded by solitary wasps in the three studied areas showed no significant correlation with climatic variables relative humidity (ρ = 0.19; p>0.15), precipitation (ρ = 0.20; p>0.10) and temperature (ρ = 0.18; p>0.15). In the Agreste region of Pernambuco, the results showed that monthly precipitation peaks between April and July. In the present study, nesting peaked between April and June, 2014, in particular in April (n=22 nests built) and May (n=21), corresponding to the beginning of the rainy season (Figure 1) and higher rainfall in the region, with 125.3 mm of precipitation being recorded in April, and 217.5 mm in May.

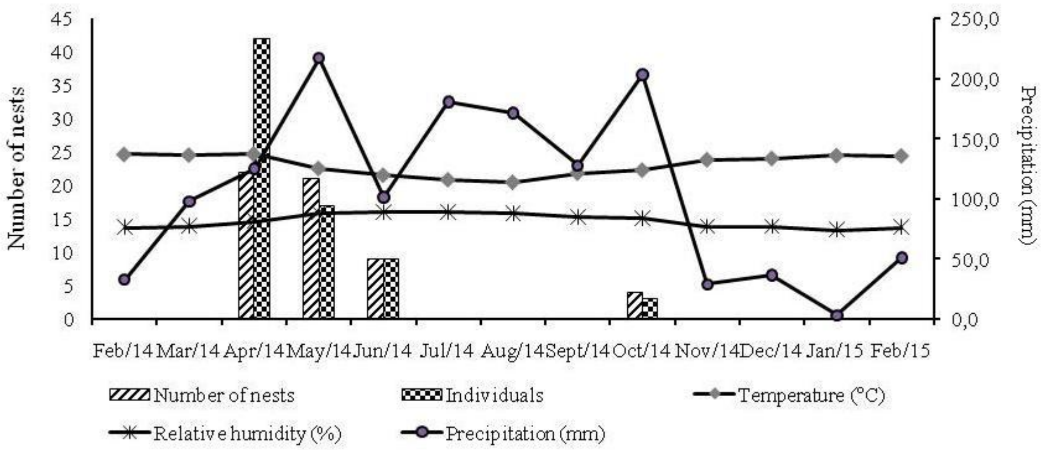

Figure 1. Monthly distribution of nests established in the trap-nests by solitary wasps, the number of individuals emerging from the nests, and the climatic parameters recorded in an agroecosystem in the Agreste region of Pernambuco, Brazil, between February 2014 and February 2015.

In the Agreste region of Pernambuco, the results showed that monthly precipitation peaks between April and July. In the present study, nesting peaked between April and June, 2014, in particular in April (n=22 nests built) and May (n=21), corresponding to the beginning of the rainy season (Figure 1), with 125.3 mm of precipitation being recorded in April, and 217.5 mm in May. The established nests of solitary wasps corresponded to the beginning of the rainy season (between April and July), when temperatures are relatively low and the relative humidity increases (CPRH, 2016). This implies an increase in the availability of feeding resources during this period. However, no significant correlation was found between climatic variables and either the number of nests built by the wasps or the number of individuals emerging from these nests. Assis and Camillo (1997) also recorded a peak in nesting during the rainy season in a trap-nest study in experimental farm fields, as did Nascimento and Garófalo (2014) and Oliveira and Gonçalves (2017), in forest fragments, where most species of solitary wasp presented a highly season pattern of nesting, coinciding with the period of greatest precipitation.

Melo and Zanella (2010) also recorded a reduction in the occupation of trap-nests by solitary wasps during periods of low precipitation, in comparison with the rainy season. The peak in nesting recorded in the present study in April and May was likely influenced by the abundant rains in the region, which resulted in the flowering of many plants, favoring the production of feeding resources, and the availability of nest-building materials. Costa and Buschini (2016) also recorded a peak in nesting by solitary wasps, in particular crabonids and vespids, during the rainy season. During the present study period, however, the rains were somewhat irregular, especially after June, 2014, when the number of nests declined abruptly.

CONCLUSION

The reduced number of solitary wasp populations recorded in the present study appear to have been related to the intense agricultural practices and in particular, the use of insecticides in cultivation environments, which reduce both the numbers of wasps and nesting sites. The establishment of a more diversified vegetation and the adoption of more ecologically-orientedland use and management strategies may favor an increase in the number of nests occupied. The study provides an important alert for farmers, even in agroecosystems, where inadequate land management and farming practices may impact local wasp populations. The study has highlighted the potential of these insects for the sustainable functioning of these systems local, where the occurrence and abundance of the different hymenopteran species vary according to the type of land use. This emphasizes the importance of the composition of agricultural habitats for the conservation and multiplication of wasps in these environments.

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