UNIVERSIDADE FEDERAL DE LAVRAS

GABRIEL DE CASTRO JACQUES

DIVERSIDADE DE POLISTINAE E O USO DE *Polistes versicolor* (HYMENOPTERA: VESPIDAE) NO CONTROLE BIOLÓGICO DE *Ascia monuste orseis* (LEPIDOPTERA: PIERIDAE)

LAVRAS – MG

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Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Entomologia, área de concentração em Controle Biológico, para a obtenção do título de Doutor.

Prof. Dr. Luis Claudio Paterno Silveira

Orientador

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APROVADA em 09 de março de 2018.

Prof. Dr. Marcel Gustavo Hermes	UFLA
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LAVRAS – MG

2018

Aos meus pais, Sérgio e Lúcia, pela educação investida em mim,

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RESUMO GERAL

Vespas sociais da subfamília Polistinae desempenham papéis ecológicos importantes como polinizadores e predadores naturais de outros artrópodes. Apesar de muitos estudos, ainda faltam informações sobre a estrutura comunitária de Polistinae em ambientes antropizados, uma importante etapa para identificar as espécies ideais a serem utilizadas em programas de controle biológico. *Ascia monuste orseis* é um praga-chave da couve-comum (*Brassica oleraceae* var. a*cephala*) e pode ocasionar prejuízos de até 100% na produção, necessitando de formas de controle deste inseto. Vespas sociais já foram registradas predando essa praga, porém não há trabalho sobre o uso destes insetos no controle biológico da mesma. Sendo assim, os objetivos deste estudo foram: i) pesquisar a fauna de vespas sociais em duas áreas antropizadas, identificando espécies com potencial para serem utilizadas no controle biológico; ii) investigar a eficiência de dois métodos de amostragem, busca ativa e armadilhas atrativas; iii) investigar o desempenho de diferentes iscas atrativas na captura de vespas sociais; iv) registrar as espécies de vespas sociais que forrageiam em uma cultura de couve-comum, correlacionando a temperatura e horário do dia no forrageio destas vespas; e v) testar a espécie *Polistes versicolor* no controle biológico de *A. monuste orseis*, no outono e inverno, período de melhor desenvolvimento da couve-comum. O trabalho foi divido em quatro experimentos: 1) diversidade de Polistinae do Instituto Federal de Educação, Ciência e Tecnologia de Minas Gerais (IFMG) – *Campus* Bambuí; 2) eficiência de diferentes métodos de amostragem na coletaa de vespas no *Campus* da Universidade Federal de Lavras; 3) sobreposição de nicho e padrão diário de atividade de vespas sociais em um cultivo de couve-comum; 4) translocação colônias de *P. versicolor* para abrigos artificias para controle de *A. monuste orseis* em couve-comum. 33 espécies de vespas sociais foram registradas no IFMG – *Campus* Bambuí, sendo *P. versicolor* a mais coletada por busca ativa e armadilhas atrativas. Já na UFLA, foram registradas 40 espécies, sendo *Mischocyttarus cassununga* a mais coletada por busca ativa e espécies do gênero *Agelaia* foram as mais coletadas por armadilhas atrativas. A metodologia de busca ativa foi mais eficiente e pela primeira vez se utilizou o melaço com isca atrativa, e este se mostrou o mais eficiente. *Polybia ignobilis*, *Protonectarina sylveirae* e *Protopolybia sedula* foram as principais espécies de vespas que forrageiam sobre a cultura da couve-comum. As interações interespecíficas entre as espécies de vespas não afetaram a coexistência destas, podendo levar a um maior controle dos insetos-praga que ocorrem na cultura. Houve um maior forrageio entre 10 e 11 horas, sendo importante conhecer esse dado para saber quando aplicar outro método de controle, contribuindo assim com o Manejo Integrado de Pragas. A translocação de colônias de *P. versicolor* para a cultura da couve, em períodos de frio e estiagem, não foi efetivo para o controle da população de *A. monuste orseis,* devido à baixa atividade de forrageio desta vespa social, e consequentemente, baixa predação sobre a praga alvo. Entretanto, é necessário uma avaliação nos períodos mais quentes e úmidos do ano, pois *P. versicolor* preda de forma efetiva diferentes espécies de lepidópteros.

Palavras-chave: Forrageio. Vespas sociais. Método de Coleta. Couve-comum.

GENERAL ABSTRACT

Social wasps of the subfamily Polistinae play important ecological roles as pollinators and natural predators of other arthropods. Despite many studies, there is still lack of information on the community structure of Polistinae in anthropogenic environments, an important step to identify the ideal species to be used in biological control programs. *Ascia monuste orseis* is a key pest of common kale (*Brassica oleraceae* var. *acephala*) and can cause losses of up to 100% in production, necessitating forms of control of this insect. Social wasps have already been registered preying on this pest, but there is no work on the use of these insects in their biological control. Thus, the objectives of this study were: i) to investigate the fauna of social wasps in two anthropic areas, identifying species with potential to be used in biological control; ii) investigate the efficiency of two sampling methods, active search and attractive traps; iii) investigate the performance of different attractive baits in the capture of social wasps; iv) to record the species of social wasps that forage in a common kale crop, correlating the temperature and time of day to the foraging habits of these wasps; and v) to test the species *Polistes versicolor* in the biological control of *A. monuste orseis*, in autumn and winter, a period of better development of common kale. The research was divided in four experiments: 1) Polistinae diversity of the Instituto Federal de Educação, Ciência e Tecnologia de Minas Gerais (IFMG) - Bambuí Campus ; 2) efficiency of different sampling methods to collect wasps at the Campus of the Universidade Federal de Lavras (UFLA); 3) niche overlap and daily pattern of social wasp activity in a common kale crop; 4) translocation of colonies of *P. versicolor* to artificial shelters to control *A. monuste orseis* in common kale. 33 species of social wasps were registered in the IFMG - Bambuí Campus, with *P. versicolor* being the most collected by active search and attractive traps. In the UFLA, 40 species were recorded, *Mischocyttarus cassununga* being the most collected by active search and species of the genus *Agelaia* were the most collected by attractive traps. The active search methodology was more efficient and for the first time molasses were used as attractive bait, and it proved to be the most efficient. *Polybia ignobilis*, *Protonectarina sylveirae* and *Protopolybia sedula* were the main species of wasps that forage on common kale crop. Interspecific interactions among wasp species did not affect the coexistence of them, which could lead to a greater control of the insect pests that occur in the crop. There was a greater foraging between 10 and 11 hours, being important to know this data to know when to apply another method of control, thus contributing to Integrated Pest Management. The translocation of colonies of *P. versicolor* to common kale during cold and drought periods was not effective for the control of the *A. monuste orseis* population, due to the low forage activity of this social wasp and, consequently, low predation on the target pest. However, an evaluation is required in the hottest and humid periods of the year, since *P. versicolor* effectively preys different Lepidoptera species.

Keywords: Forrage. Social wasps. Collection Method. Kale.

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PRIMEIRA PARTE

1 INTRODUÇÃO

Vespas sociais pertencentes à ordem Hymenoptera, família Vespidae, distribuídas em três subfamílias: Stenogastrinae, Polistinae e Vespinae. Polistinae é a única subfamília que ocorre no Brasil, dividas em três tribos: Polistini, Mischocytarini e Epiponini. No Brasil, encontramos 21 gêneros e 343 espécies dessa subfamília (HERMES; SOMAVILLA; ANDENA, 2017).

Estima-se que conhecemos menos de 10% das espécies brasileiras de insetos (LEWINSOHN; PRADO, 2005). No caso de Polistinae, esse número pode subir a 68% com 55 publicações sobre a diversidade desse grupo no Brasil (BARBOSA et al., 2016). No entanto, há um comportamento de medo das pessoas em relação ao risco de acidentes provocados pelas ferroadas desses insetos, além do desconhecimento do importante papel ecológico destes no meio ambiente (PÁDUA et al., 2017).

Esses insetos agem como polinizadores e predadores, tendo um grande potencial para estudos de biologia, comportamento e ecologia. Estudos de diversidade e distribuição de espécies são o primeiro passo em estudos de conservação, pois é necessário conhecer primeiramente os recursos naturais disponíveis em determinada área (ELPINO-CAMPOS; DEL-CLARO; PREZOTO, 2007). Além disso, o levantamento e a identificação desses insetos, principalmente em ambientes predominantemente agrícolas, é a primeira etapa para identificar as espécies ideais para serem utilizadas em programas de controle biológico de pragas (PREZOTO et al., 2006).

O uso de vespas sociais como ferramenta no controle biológico, com destaque para espécies do gênero *Polistes*, já foi elucidado por diferentes autores (PREZOTO et al., 2006; ELISEI et al., 2010) nas mais diversas culturas, como no milho (PREZOTO; MACHADO, 1999a, 1999b), algodão (KIRKTON, 1970), fumo (RABB; LAWSON, 1957; LAWSON et al., 1961), repolho (GOULD; JEANNE, 1984) e café (GRAVENA, 1983). As lagartas de Lepidoptera, principais presas de vespas sociais, são dilaceradas, maceradas e dadas como alimento às larvas, sendo a principal fonte de proteína para essas vespas em seus primeiros estágios de desenvolvimento.

Sendo assim, neste trabalho, objetivou-se obter dados sobre a diversidade de vespas sociais no *Campus* Bambuí do Instituto Federal de Educação, Ciência e Tecnologia de Minas

Gerais (Artigo 1) e no *Campus* da Universidade Federal de Lavras, testando o melaço, como uma nova isca de armadilhas atrativas para coleta de vespas sociais (Artigo 2). Após o trabalho de diversidade, fazer um levantamento das espécies de vespas sociais que forrageiam em uma cultura de couve-comum (*B. oleraceae* var. *acephala*), registrando a influência da temperatura e do horário do dia no forrageio dessas vespas (Artigo 3) e, por fim, testar a espécie *Polistes versicolor* (Hymenoptera: Vespidae), nesse cultivo, para o controle biológico de *Ascia monuste orseis* (Godart) (Lepidoptera: Pieridae), no outono e inverno, período de melhor desenvolvimento da couve-comum (Artigo 4).

2 REFERENCIAL TEÓRICO

2.1 Diversidade de vespas sociais

Insetos pertencentes à ordem Hymenoptera, família Vespidae, apresentam espécies com hábitos solitários até altamente sociais, o que faz desse grupo um modelo para se estudar o comportamento social de insetos (WILSON, 1971, 1975; HUNT, 2007). As vespas solitárias estão incluídas em três subfamílias (Euparigiinae, Masarinae e Eumeninae) e as sociais, em outras três subfamílias (Stenogastrinae, Polistinae e Vespinae) (CARPENTER, 1993; CARPENTER; MARQUES, 2001).

Vespas eussociais que ocorrem no Brasil são da subfamília Polistinae, sendo estas cosmopolitas e com alta diversidade na região Neotropical (CARPENTER; WENZEL; KOJIMA, 1996; CARPENTER; MARQUES, 2001; SILVEIRA, 2002). Espécies brasileiras de Polistinae pertencem a três tribos, Polistini, Mischocyttarini e Epiponini, com um total de 21 gêneros e 343 espécies (HERMES; SOMAVILLA; ANDENA, 2017).

A sobrevivência desses insetos depende de seu sucesso na criação de novas colônias (DEJEAN; CORBARA; CARPENTER, 1998; HUNT, 2007). A seleção de locais de nidificação foi desenvolvida sob a influência das condições climáticas e da predação por formigas e vertebrados (JEANNE, 1975; CORBARA et al., 2009). Assim, para evitar essas situações, a escolha do local de nidificação depende de certas características morfológicas, como proteção da chuva e de predadores, além da proximidade com recursos alimentares e materiais para construção do ninho (ANDENA; CARPENTER; PICKETT, 2009; SANTOS; AGUIAR; MELLO, 2010; SOUZA et al., 2010; SOUZA; PIRES; PREZOTO, 2014a).

A estrutura ambiental interfere na fauna de vespas sociais (LAWTON, 1983; SANTOS et al., 2007), pois algumas espécies só nidificam sob certas condições estruturais da vegetação, como forma e tamanho das folhas, diâmetro do tronco e presença de espinhos (HENRIQUES; DINIZ; KITAYAMA, 1992; SANTOS; GOBBI, 1998; CRUZ et al., 2006). Porém, muitas espécies apresentam alto grau de sinantropismo, nidificando preferencialmente em ambientes urbanos (FOWLER, 1983; MICHELLUTI; MONTAGNA; ANTONIALLI-JUNIOR, 2013). Isso ocorre, em razão da nidificação em edífícios urbanos reduzir a competição interespecífica e o risco da predação, especialmente por vertebrados, além de oferecer maior proteção contra variações de fatores climáticos (JUDD, 1998; MCGLYNN, 2012; MICHELLUTI; MONTAGNA; ANTONIALLI-JUNIOR, 2013).

A nidificação desses himenópteros ocorre de duas maneiras: 1 – Fundação independente, quando, geralmente, uma ou algumas fêmeas fecundadas fundam uma nova colônia, como nos gêneros *Polistes* Latreille e *Mischocyttarus* de Sausure; 2 – Enxameagem, em que várias fêmeas fecundadas e operárias são as fundadoras da colônia, ocorrendo nas vespas da tribo Epiponini (CARPENTER; MARQUES, 2001). Esses ninhos são construídos com uma mistura de saliva e fibras vegetais (PREZOTO et al., 2007) e podem ser pequenos, com uma dezena de indivíduos, como em *Mischocyttarus* (COOPER, 1998) ou enormes, com até um milhão de adultos, como no gênero *Agelaia* Lapeletier (ZUCCHI et al., 1995).

Distúrbios causados por seres humanos em ambientes naturais são os principais fatores que agem para reduzir a biodiversidade (SAMWAYS, 2007), e no caso de vespas sociais, esses impactos atingem principalmente os locais de nidificação desses insetos (DEJEAN; CORBARA; CARPENTER, 1998). Vespas sociais atuam como polinizadores (HUNT, 1991; BRODMANN, 2008; SÜHS et al., 2009; MELLO et al., 2011) e a extinção de um polinizador pode provocar a perda de espécies vegetais e começar uma “cascata de extinções interligadas” (MYERS, 1986). Algumas espécies desses himenópteros, são sensíveis às variações das condições abióticas (luminosidade, temperatura e umidade) que podem estar relacionadas à mudanças no nível de degradação ambiental, sendo assim um potencial como indicadores ambientais (SOUZA et al., 2010).

Inventários biológicos são o primeiro passo em estudos de conservação, pois é necessário conhecer primeiramente os recursos naturais disponíveis em determinada área (ELPINO-CAMPOS; DEL-CLARO; PREZOTO, 2007). Vespas sociais são facilmente amostradas em ecossistemas tropicais, pois estão ativas em todas as épocas do ano e podem ser amostradas em um período relativamente curto (KUMAR et al., 2009). O levantamento e a identificação desses insetos, principalmente em ambientes predominantemente agrícolas, é a primeira etapa para identificar as espécies ideais para serem utilizadas em programas de controle biológico de pragas (PREZOTO et al., 2006).

Há uma crescente número de publicações de estudos de diversidade de vespas sociais nos últimos dez anos (BARBOSA et al., 2016; SOUZA; BRUNISMANN; CLEMENTE, 2017), porém não há ainda um padrão na duração do estudo e na metodologia de coleta. A duração dos estudos variam entre poucos dias até 144 meses, sendo 12 meses o mais usual (BARBOSA et al, 2016). Já para a metodologia de coleta, há diferentes métodos de captura como busca ativa e armadilhas com iscas atrativas, Malaise, Möerick e de luz (SILVA; SILVEIRA, 2009; JACQUES et al., 2012; GRADINETE; NOLL, 2013; LOCHER et al., 2014; SOUZA et al., 2015a), sendo que a maioria dos estudos utiliza busca ativa e armadilhas atrativas em conjunto (BARBOSA et al., 2016). Essa grande variedade de metodologias e tempo de estudo dificulta as análises comparativas entre os diferentes estudos.

Em relação às armadilhas atrativas, há uma grande diversidade de iscas utilizadas como sucos de manga, goiaba, maracujá, laranja, caldo de sardinha e mel. Essa diversidade de iscas ocorre, principalmente, em decorrência da falta de um estudo que teste a eficiencia da melhor isca para esse método. Além disso, há uma grande variação na quantidade, disposição e duração das armadilhas (SOUZA; PREZOTO, 2006; ELPINO-CAMPOS; DEL-CLARO; PREZOTO, 2007; JACQUES et al., 2012; LOCHER et al., 2014). A padronização dessa metodologia otimizaria o tempo e os custos monetários para estabelecer essas armadilhas em campo.

Vários estudos têm sido produzidos sobre a diversidade de espécies de vespas sociais no Brasil, porém a maioria desses estudos é focada em ambientes naturais (SILVEIRA, 2002; SILVA-PEREIRA; SANTOS, 2006; SOUZA; PREZOTO, 2006; ELPINO-CAMPOS; DEL-CLARO; PREZOTO, 2007; SANTOS et al., 2007; SILVEIRA; COSTA NETO; SILVEIRA, 2008; GOMES; NOLL, 2009; SANTOS et al., 2009; SILVA; SILVEIRA, 2009; ARAB; CABRINI; ANDRANDE, 2010; PREZOTO; CLEMENTE, 2010; SOUZA et al., 2010; BONFIM; ANTONIALLI JUNIOR, 2012; SIMÕES; CUOZZO; FRIERO-COSTA, 2012; SOUZA et al., 2012; GRANDINETE; NOLL, 2013; LOCHER et al., 2014; SOUZA; PIRES; PREZOTO, 2014a; SOUZA et al., 2014b; TOGNI et al., 2014; SOMAVILLA; OLIVEIRA; SILVEIRA, 2014; SOMAVILLA; ANDENA; OLIVEIRA, 2015; SOUZA et al, 2015b; BRUNISMANN et al., 2016; ELISEI et al., 2017). (TABELA 1). No entanto, a fauna de vespas em ambientes antropofizados é pouco conhecida (JACQUES et al., 2012; OLIVEIRA; SOUZA; PIRES, 2017).

Tabela 1 - Riqueza de espécies de vespas sociais em alguns levantamentos da literatura.

Pesquisas	Número de espécies
SILVEIRA, 2002 (Floresta Amazônica)	79
SILVA; SILVEIRA, 2009 (Floresta Amazônica)	65
SOMAVILLA; OLIVEIRA; SILVEIRA, 2014 (Floresta Amazônica)	58
SOMAVILLA; ANDENA; OLIVEIRA, 2015 (Floresta Amazônica)	49
SOUZA; PIRES; PREZOTO, 2014a (Cerrado)	38
SOUZA; PREZOTO, 2006 (Cerrado e Floresta semidecidual)	38
SOUZA et al., 2010 (Mata ciliar)	36
BRUNISMANN et al., 2016 (Floresta semidecidual)	35
SOUZA et al. 2015b (Floresta semidecidual)	34
SIMÕES; CUOZZO; FRIERO-COSTA, 2012 (Cerrado)	32
LOCHER et al., 2014 (Mata ciliar)	31
ELPINO-CAMPOS; DEL-CLARO; PREZOTO, 2007 (Cerrado)	29
SOUZA et al., 2014b (Mata ciliar)	29
JACQUES et al., 2012 (Ambiente antropizado)	26
PREZOTO; CLEMENTE, 2010 (Campo Rupestre)	23
GRANDINETE; NOLL, 2013 (Cerrado)	22
TOGNI et al., 2014 (Mata Atlântica)	21
SANTOS et al., 2009 (Cerrado)	19
BONFIM; ANTONIALLI JUNIOR, 2012 (Mata Ciliar)	18
SANTOS et al., 2007 (Mata Atlântica)	18
OLIVEIRA; SOUZA; PIRES, 2017 (Ambiente antropizado)	18
SANTOS et al., 2007 (Restinga)	16
SILVA-PEREIRA; SANTOS, 2006 (Campos Rupestres)	11
ELISEI et al., 2017 (Caatinga)	10
ARAB; CABRINI; ANDRANDE, 2010 (Mata Atlântica)	10
SANTOS et al., 2007 (Mangue)	8
GOMES; NOLL, 2009 (Floresta semidecidual)	7

Fonte: Do autor (2017).

2.2 Vespas sociais no controle biológico

Vespas sociais forrageiam para encontrar água para resfriamento e construção do ninho, fibras vegetais para estruturação dos ninhos, e carboidratos, como pólen e néctar, para alimentação de adultos e larvas (RAVERET-RICHTER, 2000; LIMA; PREZOTO, 2003; JEANNE; TAYLOR 2009). Além disso, forrageiam para encontrar proteína animal, em especial insetos das ordens Diptera, Hemiptera, Hymenoptera, e principalmente Lepidoptera, que compreendem cerca de 90-95% das presas capturadas (GOBBI; MACHADO, 1986;

PREZOTO; LIMA; MACHADO, 2005; BICHARA-FILHO et al., 2009). Essas presas são dilaceradas, maceradas e dadas como alimento às larvas (RAVARET-RICHTER; JEANNE, 1985; JEANNE; HUNT; KEEPING, 1995; GOMES et al., 2007; MONTEFUSCO et al. 2017), sendo a principal fonte de proteína para vespas sociais em seus primeiros estádios de desenvolvimento (EVANS; WEST-EBERHARD, 1970). Os alimentos, carboidratos e proteínas, podem ser armazenados dentro das células para consumo posterior, constituindo uma reserva para períodos desfavoráveis (PREZOTO; GOBBI, 2003; MICHELUTTI et al., 2017).

A atividade de forrageamento é considerada um dos comportamentos mais importantes e complexos exibidos por vespas sociais (LIMA; PREZOTO, 2003) e depende da capacidade dos insetos de interagir com o meio ambiente (GOMES et al., 2007). Sob o ataque de herbívoros, as plantas emitem uma grande variedade e quantidade de substâncias voláteis induzidas por herbívoros (HIPVs), que são utilizadas pelos inimigos naturais para localizar seus hospedeiros/presas (PARÉ; TUMLINSON, 1999; HOWE; JANDER, 2008). Esse comportamento já foi registrado para vespas do gênero *Polybia* Lepeletier (RAW, 1998; REVERET-RICHTER, 1988; SARAIVA et al., 2017).

Em geral, as temperaturas mais elevadas, maior intensidade da luz, menor umidade e velocidade do ar favorecem o forrageio (LIMA; PREZOTO, 2003; ELISEI et al., 2005; RIBEIRO-JUNIOR et al., 2006). Porém, a demanda de forrageamento pode não depender apenas das variáveis climáticas, mas também das exigências biológicas da colônia (GOBBI; MACHADO, 1986; DETONI et al., 2015). Observa-se um aumento na coleta de alimentos em ninhos com número crescente de imaturos (SILVA; NODA, 2000; ANDRADE; PREZOTO, 2001, DE SOUZA et al., 2008). As presas fornecem proteína para o desenvolvimento da prole, de modo que a quantidade de presas capturadas pelos forrageiros é uma medida direta do número de imaturos e, consequentemente, a demanda proteica da colônia (CANEVAZZI; NOLL, 2011).

Vespas sociais, como outros organismos generalistas, forrageiam predominantemente sobre o recurso mais abundante, sem preferência e/ou comportamento seletivo (SANTOS et al., 2007). Porém, podem voltar a caçar em locais de sucesso da caça anterior e se alimentar, várias vezes, das mesmas espécies de presas, agindo assim individualmente, como especialistas facultativos (RAVERET-RICHTER, 1990, 2000; BICHARA-FILHO et al., 2009).

Dentre as vespas sociais, o gênero *Polistes* se destaca como um importante agente de controle biológico, pois são excelentes predadores de pragas agrícolas, principalmente de lagartas de Lepidoptera (PREZOTO et al., 2006; ELISEI et al., 2010; SOUZA et al., 2013) e em razão também da facilidade de manipulação e translocação de suas colônias para abrigos artificiais (PREZOTO & MACHADO, 1999a). A introdução de colônias de vespas desse gênero na cultura do fumo reduziu em 68% o dano causado pela lagarta *Protoparce sexta* (Johan) (Lepidoptera: Sphingidae) (RABB; LAWSON, 1957). Uma única colônia de *Polistes* pode predar 2.000 lagartas de *Pieris rapae* L., 1758 (Lepidoptera: Pieridae), praga da couve, durante seu ciclo de desenvolvimento (MORIMOTO, 1961). Observou-se uma redução de 77,16% na incidência de *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) em plantações de milho com a utilização de *Polistes simillimus* Zikan, 1951 (Hymenoptera: Vespidae) (PREZOTO & MACHADO, 1999b). Além disso, a presença de vespas do gênero *Polistes* em diferentes culturas está associada à diminuição de danos causados por pragas em plantações de algodão (KIRKTON, 1970), fumo (LAWSON et al., 1961), repolho (GOULD; JEANNE, 1984) e café (GRAVENA, 1983), mostrando a importância desse gênero para estudos com controle biológico de pragas.

Polistes versicolor (Olivier, 1791) (Hymenoptera: Vespidae) também já foi testada em estudos com controle biológico. Em 120 horas de observação, 315 retornos das forrageadoras de *P. versicolor* foram com presas, sendo principalmente lagartas de lepidópteros (ELISEI et al., 2010). Oitenta e nove presas, sendo 95% de lepidópteros, foram predadas por essa vespa em Juiz de Fora, MG (PREZOTO et al., 2006). A ação predatória dessa vespa também foi estudada sobre *Chlosyne lacinia saundersii* (Doubleday & Hewitson, 1849) (Lepidoptera: Nymphalidae) (CAMPOS-FARINHA; PINTO, 1996) e sobre *Heraclides anchysiades capys* (Hübner, 1809) (Lepidoptera: Papilionidae) (MARQUES, 1996; MARQUES et al., 2005).

A couve-comum (*Brassica oleraceae* var. *acephala*) pertence à família das brássicas, que constituem a família mais numerosa em termos de espécies oleáceas, totalizando 14 hortaliças, sendo de grande importância na nutrição humana e com melhor desenvolvimento no outono e no inverno, porém, apresenta boa adaptação a climas variados (FILGUEIRA, 2000). Várias espécies de insetos pragas atacam essa hortaliça, como a mosca branca, *Bemisia tabaci* (Genn., 1889) (Hemiptera: Aleyrodidae), e os pulgões *Brevicoryne brassicae* (L., 1758) e *Myzus persicae* Sulzer, 1776 (Hemiptera: Aphididae) (GALO et al., 2002). Esses insetos debilitam as plantas, sugando a seiva e introduzindo toxinas em seu sistema vascular, causando deformações dos tecidos foliares e formação de galhas, além de contribuir para o aparecimento de fumagina sobre a folhagem, por meio da excreção de *honeydew* (GALO et al., 2002; HAJI; FERREIRA; MOREIRA, 2004; SALVADORI; PEREIRA; SILVA, 2005; VAN EMDEN, 2013).

Diversos lepidópteros também atacam a couve-comum, como a lagarta-rosca, *Agrotis ipsilon* (Hufnagel, 1776) (Noctuidae), lagarta-mede-palmo, *Trichoplusia ni* (Hübner, 1803) (Noctuidae), curuquerê-da-couve, *Ascia monuste orseis* (Godart, 1819) (Pieridae), e traça-das-crucíferas, *Plutella xylostella* (L., 1758) (Plutellidae) (GALLO et al., 2002). *A. monuste orseis*, constitui uma das pragas-chave dessas culturas na região Neotropical, principalmente no Brasil (SHIMA; GOBBI, 1981; BORTOLI; BANZATO; FORNER, 1983; BARROS; ZUCOLOTO, 1999). As largatas dessa espécie se alimentam das folhas, levando a grandes perdas na cultura (GALLO et al., 2002), podendo ocasionar prejuízos de até 100% na produção (NOMURA; YAMASHITA, 1975; VENDRAMIM; MARTINS, 1982).

As fêmeas dessa praga ovipositam na face inferior das folhas, principalmente de folhas jovens (BITTENCOURT-RODRIGUES; ZUCOLOTO, 2005, 2009). Após quatro ou cinco dias, eclodem as lagartas que, durante o primeiro e o segundo instares, alimentam-se do local onde ocorreu a oviposição. Já lagartas de quarto e quinto ínstares apresentam uma razoável mobilidade, podendo migrar para outras folhas (BARROS-BELLANDA; ZUCOLOTO, 2003) e até de um cultivar para outro (CATTA-PRETA; ZUCOLOTO, 2003). O período larval dura cerca de 20 a 25 dias, seguido de fase pupal de duração média de 11 dias (BARROS; ZUCOLOTO, 1999).

O controle de *A. monuste orseis* é executado, principalmente, pela aplicação de inseticidas como carbaril, deltametrina, paratiom metílico, permetrina e triclorfom (ANDREI, 2013). Esses produtos químicos sintéticos podem acarretar diversos problemas, tais como resíduos nos alimentos, morte de inimigos naturais, intoxicação de aplicadores e aparecimento de populações de pragas resistentes. Sendo assim, uma saída para a diminuição do uso desses produtos é o uso de agentes de controle biológico.

Vespas sociais já foram registradas predando essa praga, dentre as quais destacam-se as do gênero *Polybia* (Hymenoptera: Vespidae) (PICANÇO et al., 2010), porém poucos trabalhos relatam a importância dessa predação e a utilização de vespas no controle biológico de pragas da agricultura (RABB; LAWSON, 1957; MORIMOTO, 1961; PREZOTO & MACHADO, 1999a, 1999b).

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SEGUNDA PARTE – ARTIGOS

ARTIGO 1 – DIVERSITY OF SOCIAL WASPS (HYMENOPTERA, VESPIDAE: POLISTINAE) IN AN AGRICULTURAL ENVIRONMENT IN BAMBUÍ, MINAS GERAIS, BRAZIL

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Abstract

Studies on the diversity of social wasps in agricultural environments represent an important step to identify ideal species to be used in biological pest control programs. There is a growing effort to recognize the diversity of these insects, but information on anthropized environments is still rare. This study focused on obtaining data on the diversity of social wasps in a predominantly agricultural area in Bambuí, Minas Gerais, Brazil, and identifying, through dominance, species with potential use in biological control studies. Sampling was conducted from July 2012 to July 2014 with two type of wasps' capture methods: attractive traps and active search. This research confirms that a well diversified environment, even if anthropized, is rich in social wasp species, with a total of twenty-nine species. In addition, the great number of collected species shows the importance of a long-term survey and the use of more than one method of capture. The high rate of collections of *Polistes versicolor* in a predominantly agricultural environment, coupled with other studies on this species as a predator of lepidopteran caterpillars, suggests the use of this species as a tool in biological control of pests.

Keywords: Biodiversity, *Polistes versicolor*, Polistinae.

Introduction

Social wasps (Vespidae) are insects belonging to the order Hymenoptera and may play an important ecological role in the environment, acting as pollinators (Hunt, 1991; Brodmann, 2008; Mello et al., 2011) and predators (Prezoto & Machado, 1999; Prezoto et al., 2006; Silveira et al., 2008; Gomes & Noll, 2009). This family includes solitary species (Euparigiinae, Masarinae and Eumeninae), and others with different degree of sociality (Stenogastrinae, Polistinae and Vespinae) (Carpenter, 1993; Carpenter & Marques, 2001).

In this family, those wasps belonging to the subfamily Polistinae are eusocial, cosmopolitan and highly diverse in the Neotropical region (Carpenter et al., 1996; Carpenter & Marques, 2001; Silveira, 2002). Brazilian species of Polistinae belong to three tribes, namely Polistini, Mischocyttarini and Epiponini, with 23 genus e 319 species (Carpenter & Marques, 2001).

The survival of these social wasps depends on their success in creating new colonies (Dejean et al, 1998; Hunt, 2007). The choice for a nesting site depends on certain morphological characteristics, such as protection from rain and predators (e.g., ants and vertebrates), besides proximity to food resources and material for nest construction (Andena et al., 2009; Santos et al., 2010; Souza et al., 2010; Souza et al. 2014a).

Disturbances caused by humans in natural environments are the main factors which may reduce their biodiversity (Samways, 2007). Social wasps act as pollinators (Suhs et al., 2009) and the extinction of a pollinator can cause loss of plant species and trigger a "cascade of linked extinctions" (Myers, 1986). Some Hymenoptera species are sensitive to variations of abiotic conditions (light, temperature and humidity), which may be related to changes in the level of environment degradation, thus representing potential environmental indicators (Souza et al., 2010).

Biological inventories are the first step for the development of preservation studies, since it is essential to know first of all which resources are available in a particular area (Elpino-Campos et al., 2007). Social wasps are easily sampled because they forage and return to a core area (nest). The survey and identification of these insects, especially in predominantly agricultural environments, are the first steps to identify ideal species to use in biological control of pests programs (Prezoto et al., 2006).

Several studies have been developed on the diversity of species of social wasps in Brazil, however, most of them focused only natural environments (Silveira, 2002; Silva-

Pereira & Santos, 2006; Souza & Prezoto, 2006; Elpino-Campos et al., 2007; Santos et al. 2007; Silveira et al., 2008; Gomes & Noll, 2009; Silva & Silveira, 2009; Santos et al., 2009; Souza et al., 2010; Bonfim & Antonialli Junior, 2012; Simões et al., 2012; Souza et al., 2012; Grandinete & Noll, 2013; Locher *et al*. 2014; Souza et al., 2014a, 2014b). Therefore, the fauna of wasps in anthropized environments is still poorly known (Jacques et al., 2012). The objective of this study was to obtain data on the diversity of social wasps in a predominantly agricultural area, Instituto Federal de Educação, Ciências e Tecnologia de Minas Gerais (IFMG), Bambuí campus, Minas Gerais, Brazil, and to identify, through dominance, species with potential for use in biological control studies.

Material and Methods

This research was conducted at the Instituto Federal de Educação, Ciência e Tecnologia de Minas Gerais (IFMG), campus Bambuí, Minas Gerais, Brazil. The campus has a total area of 328 ha, with one anthropic site, but very diverse, with a predominance of buildings and agricultural areas. 175 hectares are used for agricultural crops (corn, beans, sugar cane, orange, banana, coffee and vegetables) and pastures, and 34 acres of buildings, most being close to the cultivars. Sampling was conducted in agricultural environments from July 2012 to July 2014 with two types of data capture: attractive traps and active search.

The traps were made with two-liter plastic soft-drink bottles, with three triangular lateral openings (2 x 2 x 2 cm) at a 10 cm distance from the base (Souza & Prezoto, 2006). Substances used to attract insects were: 1- natural passion fruit juice (*Passiflora edulis* f. *flavicarpa* Deg. - Passifloraceae) prepared with 1 kg of fruit blended with 250g granulated sugar plus two liters of water; 2- sardine broth (*Sardinella brasiliensis* Steindachner 1789), which included two cans of sardines plus two liters of water; 3- pure honey; 4 - sugarcane molasses diluted to 50%.

Five bottles with 150 ml attractive substance for each type of bait, were assembled in eight dates, with total for forty bottles per attractive substance type (160 traps in total). These traps were set up next to the cultivars at the IFMG campus, at a 1.5 m height above the ground. The traps were active for seven days. After that time, the wasps collected were removed and preserved in 70% alcohol for later identification.

Active searches were conducted throughout the agricultural area of the campus Bambuí at the IFMG. Trunks of trees and other natural cavities, broad-leaved vegetation, flowers and edifications were surveyed and the wasps were collected with the aid of entomological nets (Souza & Prezoto, 2006; Elpino-Campos et al., 2007).

Species collected were identified using entomological keys (Richards 1978, Carpenter 2004) and were confirmed by Dr. Orlando Tobias Silveira from Emílio Goeldi Museum of Belém, Pará State, Brazil. Diversity was calculated by the Shannon-Wiener (H ') index, and the dominance by the Berger-Parker index (D_{PB}), through the DivEs program - Diversity of Species v3.0.3, in the base 10 logarithmic (Rodrigues, 2014).

Results and Discussion

Five hundred and twenty-seven social wasps of 8 genus and 29 species were collected, with a total diversity index of 1.7406 (Table 1). This great richness of species, compared with that observed by other authors (Table 2), is explained by the fact that many species of social wasps present high level of synanthropism (Fowler, 1983; Michulleti et al, 2013).

The study area has a very diverse environment, which may help explain the large number of species collected, since environments that are structurally more heterogeneous and complex may favor the coexistence of a larger number of species due to the greater availability of microhabitats, greater protection against predators and greater disposal and diversity of food resources and substrate for nidification (Santos et al, 2007; Souza et al, 2012).

There was high dominance (Dpb= 0.2789) of few species. *Polistes versicolor* (Olivier, 1791) presented the greater rate of total frequency (36.81%), it has been collected 194 times. It also had the higher frequency in capture by attractive traps (34.35%) and active search (47.47%). Such occurrence may be explained by the fact that there are *P. versicolor* nests in both urban buildings and vegetation (Oliveira et al., 2010; Torres et al., 2014a), which makes it easy to be found.

Table 1. Richness, diversity and dominance of social wasp species collected at the Instituto Federal de Educação, Ciência e Tecnologia de Minas Gerais (IFMG), Campus Bambuí, Minas Gerais, Brazil. September, 2014.

		Active search		**Traps**		**Total**	
	Species	Abundance	Frequency relative (%)	Abundance	Frequency relative (%)	Abundance	Frequency relative (%)
1	*Agelaia centralis* (Cameron, 1907)	1	1.01%	127	29.67%	128	24.29%
2	*Agelaia multipicta* (Haliday, 1836)	1	1.01%	47	10.98%	48	9.11%
3	*Apoica gelida* Van der Vecht,1973	0	0.00%	2	0.47%	2	0.38%
4	*Brachygastra lecheguana* (Latreille, 1824)	1	1.01%	2	0.47%	3	0.57%
5	*Mischocyttarus bahiae* Richards, 1949	1	1.01%	0	0.00%	1	0.19%
6	*Mischocyttarus cassununga* (R. Von. Ihering, 1903)	2	2.02%	3	0.70%	5	0.95%
7	*Mischocyttarus cerberus* (Richards, 1940)	1	1.01%	1	0.23%	2	0.38%
8	*Mischocyttarus drewseni* Sausurre, 1857	2	2.02%	2	0.47%	4	0.76%
9	*Mischocyttarus ignotus* Zikán, 1949	3	3.03%	0	0.00%	3	0.57%
10	*Mischocyttarus latior* (Fox, 1898)	1	1.01%	0	0.00%	1	0.19%
11	*Mischocyttarus matogrossensis* Zikán, 1935	1	1.01%	0	0.00%	1	0.19%
12	*Mischocyttarus nomurae* Richards, 1978	1	1.01%	0	0.00%	1	0.19%
13	*Mischocyttarus paraguayensis* Zikán, 1935	6	6.06%	0	0.00%	6	1.14%
14	*Mischocyttarus rotundicolis* (Cameron, 1912)	12	12.12%	1	0.23%	13	2.47%
15	*Polistes actaeon* Haliday, 1836	1	1.01%	0	0.00%	1	0.19%
16	*Polistes satan* Bequaert, 1940	3	3.03%	8	1.87%	11	2.09%
17	*Polistes simillimus* Zikán,1951	2	2.02%	21	4.91%	23	4.36%
18	*Polistes versicolor* (Olivier, 1971)	47	47.47%	147	34.35%	194	36.81%
19	*Polybia bifasciata* Saussure, 1854	1	1.01%	0	0.00%	1	0.19%
20	*Polybia chrysothorax* (Lichtenstein, 1796)	1	1.01%	12	2.80%	13	2.47%
21	*Polybia erythrothorax* (Richards, 1978)	2	2.02%	0	0.00%	2	0.38%
22	*Polybia ignobilis* (Haliday, 1836)	0	0.00%	25	5.84%	25	4.74%
23	*Polybia jurinei* Saussure, 1854	0	0.00%	18	4.21%	18	3.42%
24	*Polybia occidentalis* (Olivier, 1971)	2	2.02%	2	0.47%	4	0.76%

25	*Polybia paulista* (R. Von. Ihering, 1896)	4	4.04%	0	0.00%	4	0.76%
26	*Polybia rejecta* (Fabricius, 1978)	1	1.01%	0	0.00%	1	0.19%
27	*Polybia sericea* (Olivier, 1971)	0	0.00%	10	2.34%	10	1.90%
28	*Protopobybia sedula* (Saussure, 1854)	1	1.01%	0	0.00%	1	0.19%
29	*Synoeca cyanea* (Fabricius, 1775)	1	1.01%	0	0.00%	1	0.19%
	Total of individuals	**99**		**428**		**527**	
	Richness of species (S`)	**25**		**16**		**29**	
	Shannon-Wiener (H`) Index	**0,9402**		**0,8004**		**1,7406**	
	Berger-Parker (Dpb) Index	**0,4747**		**0,3435**		**0,2789**	

Table 2. Comparison between the total number of species in this research work (*) and other surveys in the literature.

Researches	**Number of species**
Silveira, 2002 (Amazon Rainforest)	79
Silva & Silveira, 2009 (Amazon Rainforest)	65
Souza et al., 2014a (Cerrado)	38
Souza et al., 2012 (Atlantic Forest)	38
Souza & Prezoto, 2006 (Cerrado and Semidecidual Forest)	38
Souza et al., 2010 (Riparian)	36
Simões et al., 2012 (Cerrado)	32
Locher et al., 2014 (Riparian Vegetation)	31
*Present work (Agricultural Environment)	29
Elpino-Campos et al., 2007 (Cerrado)	29
Souza et al., 2014b (Riparian)	28
Jacques et al., 2012 (Anthropized environment)	26
Grandinete & Noll, 2013 (Cerrado)	22
Santos et al., 2009 (Cerrado)	19
Bonfim & Antonialli Junior, 2012 (Riparian Vegetation)	18
Santos et al., 2007 (Atlantic Forest)	18
Santos et al., 2007 (Restinga Vegetation)	16
Silva-Pereira & Santos, 2006 (Campos Rupestres)	11
Arab et al., 2010 (Atlantic Forest)	10
Santos et al., 2007 (Mangrove)	8
Gomes & Noll, 2009 (Semidecidual Forest)	7

Wasps of *Polistes* are excellent predators of agricultural pests, especially caterpillars of Lepidoptera (Prezoto et al., 2006; Elisei et al., 2010; Souza et al., 2013). Thus, the agrarian environment of the campus may have provided a favorable environment for *P. versicolor,* because the caterpillars present in different agricultural areas are the main feed of immature insects that develop in the colony (Raveret-Richter, 2000). In 120 hours of observation, 315 returns of *P. versicolor* foragers included preys, mostly lepidopteran caterpillars (Elisei et al., 2010). Eighty-nine preys (95% of Lepidoptera) were captured by this species in Juiz de Fora, MG (Prezoto et al., 2006). The predatory activity of this wasp was also studied on *Chlosyne lacinia saundersii* (Doubleday & Hewitson, 1849) (Lepidoptera: Nymphalidae) (Campos-Farinha & Pinto, 1996) and on *Heraclides anchysiades capys* (Hübner, 1809) (Lepidoptera: Papilionidae) (Marques, 1996, 2005). Moreover, the presence of wasps of the genus *Polistes* in different cultures is associated with reduced damage caused by pests on cotton (Kirkton, 1970), tobacco (Lawson, et al., 1961), cabbage (Gould & Jeanne 1984), coffee (Gravena, 1983) and corn (Prezoto & Machado, 1999), showing the importance of this genus for studies on the biological control of pests.

Agelaia centralis (Cameron, 1907) and *Agelaia multipicta* (Haliday, 1836) also showed high frequency in the community in collections using attractive traps (29.67% and 10.98%, respectively). Some species of genus *Agelaia* Lepeletier, 1836 can build colonies with a population estimated in up to a million of adults (Zucchi et al., 1995), which means a greater ability of foraging by a greater amount of wasps and increased chances of finding specimen of this group (Hunt et al., 2001). Furthermore, these wasps have a scavenger habit, especially being collected by the attractive sardine broth, which is used as an additional source of protein for their larvae (Prezoto & Souza, 2006). The high prevalence of this genus was also reported in different ecossystems in Brazil (Gomes & Noll, 2009; Arab et al., 2010; Grandinete & Noll, 2013; Locher et al., 2014).

The most collected genus was *Mischocyttarus* De Saussure, 1853, with 10 species, and *Mischocyttarus bahiae* Richards, 1949 was first recorded for the state of Minas Gerais, which shows the importance of surveys on social wasp richness and diversity. Nests of *Mischocyttarus* are easily found in edifications, making it easy to locate it (Alvarenga et al., 2010). Moreover, this genus consists of the largest group of social wasps, with 245 species of eleven subgenera, which added to fact that only a few have been studied for richness and diversity, increases the chance of unpublished records (Cooper, 1998; Silveira, 2008).

Of the 28 species found, 25 were located in their colonies. This was due to the long period of data collection, which is important, because collection must be carried out in the warmer and wetter periods of the year, considering that there is a positive correlation between these abiotic factors and the number of species and colonies (Souza et al., 2014a). This is due to a greater availability of nesting sites, protection from predators and increased availability and diversity of food resources on those periods (Prezoto et al., 2006; Elpino-Campos et al., 2007).

The methodology of active search, considering the richness of the collected species, was more effective than the use of traps (Table 1), whereas sixteen species were collected solely through this method. This has also been observed in other works (Silveira, 2002; Souza & Prezoto, 2006; Elpino-Campos et al., 2007; Jacques et al., 2012; Loucher et al., 2014; Souza et al., 2014b).

Four species, *Apoica gelida* Van der Vecht, 1973, *Polybia ignobilis* (Haliday, 1836), *Polybia jurinei* Saussure, 1854 and *Polybia sericea* (Olivier, 1971), were collected solely through traps. This may be related to the fact that social species have the habit of nesting in one place and feeding in another (Pereira & Santos, 2006). Furthermore, the genus *Apoica* Lepeletier, 1836 are generally captured by traps, because they mainly forage at night (Hunt et al., 1995; Pickett & Wenzel, 2007), making it less likely to be captured by active search during the day. These results demonstrate the importance of using more than one method to record the highest possible number of wasp species (Jacques et al., 2012).

This work confirms that a well-diversified environment, even if anthropized, such as the Bambuí campus of the Instituto Federal de Educação, Ciência e Tecnologia de Minas Gerais (IFMG), Brazil, includes a rich amount of species of social wasps. In addition, the great number of collected species, shows the importance of a long-term survey and the use of more than one method of collection.

The high rate of collections of *Polistes versicolor* in a predominantly agricultural environment, coupled with other studies on this species as a predator of lepidopteran caterpillars, suggests the use of this species as a tool in the biological control of pests.

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ARTIGO 2 - EVALUATING THE EFFICIENCY OF DIFFERENT SAMPLING METHODS TO SURVEY SOCIAL WASPS (VESPIDAE, POLISTINAE) IN AN ANTHROPIZED ENVIRONMENT IN SOUTHEAST BRAZIL

Artigo Submetido ao periódico *Sociobiology*.

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Abstract

Social wasps play important ecological roles, such as the natural biological control of other arthropods as well as major components of the flower-visiting insect guild. Despite many studies focusing on the survey of these organisms in Brazil, information on the community structure of polistines in anthropized environmets are still rare. The goals of the present study were: i) to survey the social wasp fauna in an anthropized area in the transition of Cerrado and Atlantic Forest; ii) to investigate the efficiency of two sampling methods, namely active search for wasps and the use of attractive traps; iii) to investigate the performance of different attractive baits in the capture success of social wasps in the study area. Collecting of social wasps were conducted by actively searching for individuals and by the use of attractive traps. A total of 40 species were recorded, with *Agelaia multipicta* and *Agelaia vicina* species being the most frequently collected with attractive traps and *Mischocyttarus cassununga* by actively searching for wasps. In all analyses performed (except when comparing abundance of social wasps considering the molasse bait and the active search), actively searching for wasps was the best method. This is also highlighted by the fact that the time spent actively capturing polistines was considerably lower than the time (and costs) than the traps were left in the field. Active search, as demonstrated by previous studies, remains as the best capturing methodology when surveying Neotropical social wasps, either in natural or anthropized environments.

Keywords: Baits, diversity, Neotropical, polistine wasps, survey.

Introduction

Social wasps occurring in Brazil belong to the cosmopolitan Polistinae, which are particularly speciose in the Neotropics (Silveira, 2002). Three polistine tribes are found in Brazil, with totals for the subfamily counting to as much as 21 genera and 343 species (Hermes et al., 2017), corresponding to approximately 35% of the world fauna (Prezoto et al., 2007).

These insects play important roles in the environments, acting as potential pollinators (Clemente et al., 2013; Clemente et al., 2017) and, specially, as predators (Prezoto & Machado, 1999; Silveira et al., 2008; Souza et al., 2013a; Montefusco et al., 2017). Lepidopteran larvae are among the preferred prey of social wasps, including those of economic importance in various crops such as tomato, coffee, maize and others (Prezoto & Machado, 1999; Prezoto et al., 2006; Elisei et al., 2010; Freitas et al., 2015). Some species of polistine wasps have already been employed in biological control programs in Brazil (Prezoto & Machado, 1999).

Survival of the colonies is directly tied to their success in founding and establishing new nests (Dejean et al., 1998; Hunt, 2007). Nesting site choice by polistines is highly influenced by climatic factors as well as selective pressures resulting from predation by vertebrates and ants (Souza et al., 2013b; Souza et al., 2017). Besides protection from unfavorable weather and predators, nesting sites are usually chosen based on resource avilability, such as food and nest construction materials (Souza et al., 2010, Souza et al., 2014a).

Environmental structure directly affects the social wasp fauna (Santos et al., 2007), since some species will only nest under specific vegetational conditions, such as shape and size of the leaves, trunk diameter and presence of thorns (Santos & Gobbi, 1998; Cruz et al., 2006). However, several species are highly sinantropic, nesting preferably in urban environments (Michelutti et al., 2013; Oliveira et al., 2017) due to higher prey and protected nesting site availability (Prezoto et al., 2007).

Human disturbance, such as direct colony destruction, excessive use of insecticides (Souza et al., 2012), and forest fragmentation strongly decrease nesting possibilities (Dejean et al., 1998; Souza et al., 2010; Souza et al., 2014b). Also, some species are sensitive to changes in abiotic factors (luminosity, temperature and humidity) that may be related to environmental degradation, making them good indicators of environmental quality (Souza et al., 2010). In this context, biological surveys are essential to support conservation actions and programs (Elpino-Campos et al., 2007). Since polistines are easily surveyed in tropical systems and are active during all seasons, and may be sampled in a short period of time (Kumar et al., 2009), their study in a conservationist perspective is strongly recommended.

Several studies dealing with commnunity structure of social wasps have been carried out in Brazil in the past years, but they are mostly focused in natural environments (Silveira, 2002; Silva-Pereira & Santos, 2006; Souza & Prezoto, 2006; Elpino-Campos et al., 2007; Santos et al., 2007; Silveira et al., 2008; Gomes & Noll, 2009; Silva & Silveira, 2009; Santos et al., 2009; Arab et al., 2010; Prezoto & Clemente, 2010; Souza et al., 2010; Bonfim & Antonialli Junior, 2012; Simões et al., 2012; Souza et al., 2012; Grandinete & Noll, 2013; Locher et al., 2014; Souza et al., 2014a, 2014b; Togni et al., 2014; Somavilla et al., 2014, 2015; Souza et al., 2015; Brunismann et al., 2016; Elisei et al., 2017). The polistine fauna of anthropized areas, however, is still poorly investigated (Jacques et al., 2012, 2015; Oliveira et al., 2017). With that in mind, the goals of the present study are: i) to survey the social wasp fauna in an anthropized area in the transition of Cerrado and Atlantic Forest in Southern Minas Gerais, Brazil; ii) to investigate the efficiency of two sampling methods, namely active search for wasps and the use of attractive traps; and iii) to investigate the performance of different attractive baits in the capture success of social wasps in the study area.

Material and Methods

The study was conducted in the Federal University of Lavras (UFLA), Lavras, Minas Gerais, Brazil, which is located at 21º 14’ 30” S and 45º 00’ 10” W. The altitude is approximatelly 918 m above sea level, and the climate is characterized as Cwa Köppen, with rainy summers and dry winters. The mean annual pluviosity is 1.411 mm and the mean annual temperature is 19,3ºC.

The university´s campus has a total area of 508 ha, which is highly anthropized, with 117 ha of urban settlements and 207 ha of crops. From the remaining 184 ha, only 33,23 ha comprehend Atlantic Forest and Cerrado fragments. Collecting of social wasps in the study area was conducted from April 2014 to June 2015, by actively searching for individuals and with the aid of attractive traps.

Active searches for wasps were conducted in the entire area of the campus, totaling 14 field incursions of five hours each, totaling 70 hours of sampling effort (two collectors = 140 hours). Flowering plants, logs, vegetation close to lakes, and buildings were inspected and the wasps collected with entomological nets (Souza & Prezoto, 2006; Elpino-Campos et al., 2007).

Attractive traps were made using plastic bottles with three triangular openings (2 x 2 x 2 cm) at approximately 10 cm from the base (Souza & Prezoto, 2006). Four types of attractive baits were used: a) natural passion fruit juice (*Passiflora edulis* f. *flavicarpa* Deg.) prepared with 1 kg of fruit blended with 250g granulated sugar plus two liters of water; b) sardine stock, using two sardine cans mixed with two litters of water (Souza & Prezoto, 2006); c) pure honey; and d) 50% diluted sugar cane molasses (Jacques et al., 2015).

The traps were installed in seven different fragments of the forest remnants inside the campus, with 150 ml attractive substance placed in eight bottles each, totaling 32 traps per fragment. The traps were placed at 1,5 m from the ground and at 10 m appart from each other (Fig 1). The traps stayed in the field for seven days, when the wasps were removed and preserved in 70% alcohol. Social wasps were identified to species level using keys (Richards, 1978; Carpenter, 2004) and by specialists (Dr. James M. Carpenter, AMNH, and MGH and MMS coauthors of the study).

The diversity of wasps was calculatd with the Shannon-Wiener (H') index and the dominance with the Berger-Parker (D_{pb}) index, using the software Past (Hammer et al., 2005). To evaluate sampling effort success we constructed species accumulation curves using the observed richness with a 95% confidence interval, under the Bootstrap 1 estimator in the software EstimateS 9.1.0 (Cowell, 2013). This estimator uses information from all collected species instead of restricting the analysis to rare species (Santos, 2003).

To test which bait was more successful regarding species richness and abundance, generalized linear mixed models (GLMM) were performed assuming sampling date as the random variable, reducing the effects of sampling and repeated measures, and the different baits and active search as explicative variables. Lastly, Tukey contrast analyses with Bonferroni correction (i.e., multiple comparisons of means) were employed as pairwise comparisons. Poisson errors distribution was assumed for both models and statistical analyses were performed using the software R (R Development CoreTeam, 2017).

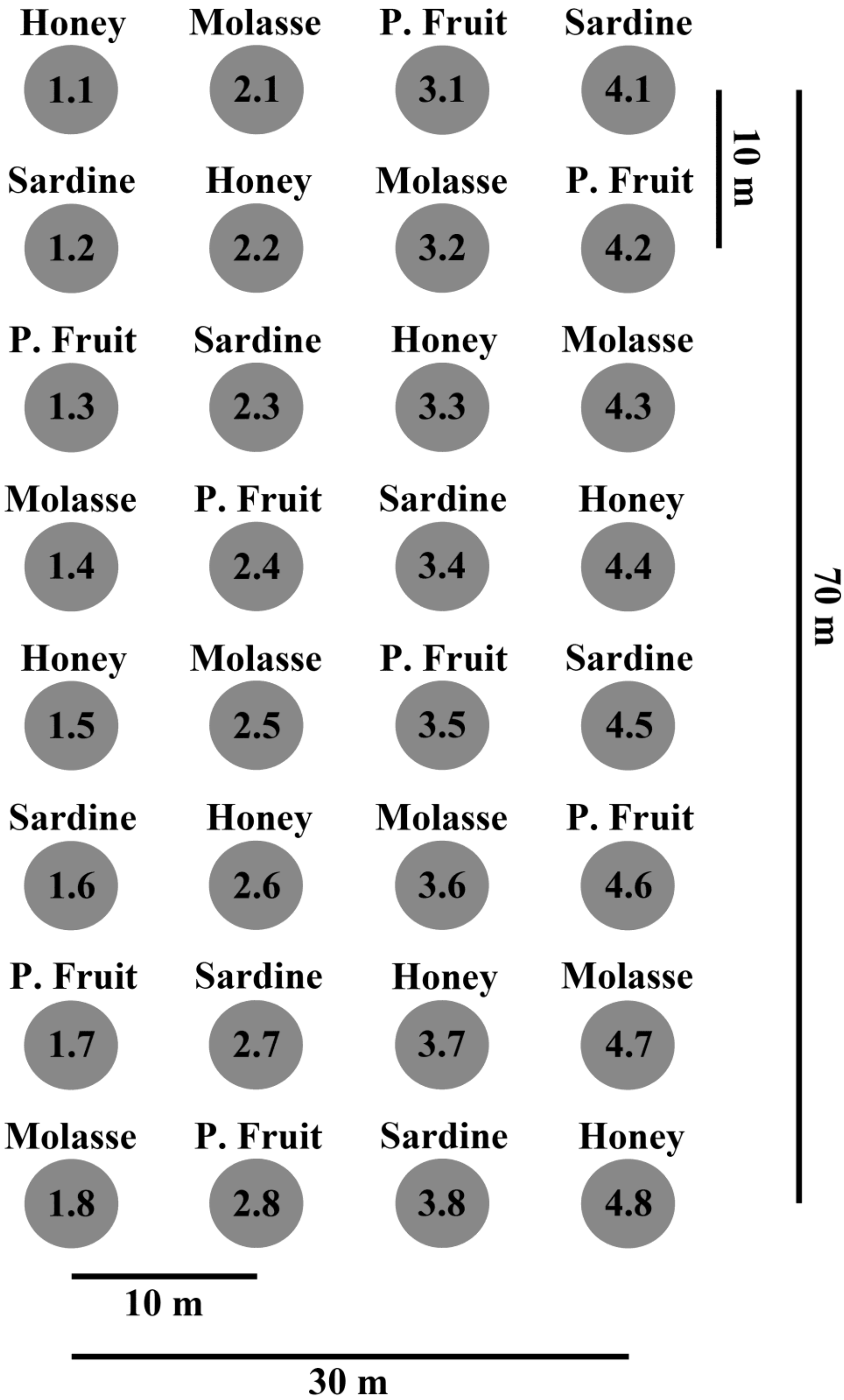

Fig. 1. Distributional scheme of the attractive bait-traps used in the present study.

Results and Discussion

A total of 11 genera and 40 species of social wasps were collected during the study, with a total diversity index of 2,495 (Table 1). The present collecting effort resulted in the fifth highest Polistine richness considering similar studies in Brazil (Table 2) (Barbosa et al., 2016), only behind those conducted in the Amazon (Silveira, 2002; Silva & Silveira, 2009; Somavilla et al., 2014; Somavilla et al., 2015). The high richness found herein may be a result of the high sinantropic affinity presented by several social wasp species (Michelutti et al., 2013; Oliveira et al., 2017), despite colony development and productivity being negatively affected by the urban environment (Michelutti et al., 2013; Torres et al., 2014). However, nesting in buildings reduces interespecific competition, predation by vertebrates, and offers better protection against climatic adversities (McGlynn, 2012; Michelutti et al., 2013).

Another factor that may contribute to a higher richness of social wasps in urban areas is likely a methodological one, because dense vegetation and nest camouflage will certainly difficult sampling when actively searching for these insects inside forests (Souza et al., 2010). Also, the environmental structure of the study area is highly complex and heterogeneous, with human constructions, crops, and Atlantic Forest and Cerrado fragments, which may favor coexistence of a higher number of species due to a greater offering of microhabitats and resources, as well as nesting materials and substrates (Santos et al., 2007; Souza et al., 2012).

Table 1. Richness, diversity and dominance of social wasp species collected at *Universidade Federal de Lavras*, Lavras, Minas Gerais, Brazil.

Taxon	**Active Search**		**Attractive Traps**		**Totals**	
	Nº of individuals	Frequency (%)	Nº of individuals	Frequency (%)	Nº of individuals	Frequenc y (%)
Agelaia centralis (Cameron)	2	0,85	0	0,00	2	0,18
Agelaia multipicta (Haliday)	1	0,42	201	23,00	202	18,20
Agelaia vicina de Saussure	1	0,42	351	40,16	352	31,71
Apoica pallens (Fabricius)	5	2,12	9	1,03	14	1,26
Brachygastra lecheguana (Latreille)	3	1,27	3	0,34	6	0,54
Clypearia augustior (Ducke)	2	0,85	0	0,00	2	0,18
Mischocyttarus ignotus Zikán	9	3,81	4	0,46	13	1,17
Mischocyttarus cassununga (R. Von. Ihering)	68	28,81	3	0,34	71	6,40
Mischocyttarus drewseni de Sausurre	3	1,27	5	0,57	8	0,72
Mischocyttarus paraguayensis de WillinK	3	1,27	0	0,00	3	0,27
Mischocyttarus labiatus Fabricius	5	2,12	6	0,69	11	0,99
Mischocyttarus rotundicolis (Cameron)	1	0,42	0	0,00	1	0,09
Mischocyttarus socialis (de Saussure)	1	0,42	3	0,34	4	0,36
Mischocyttarus sp.	2	0,85	0	0,00	2	0,18
Parachartergus fraternus (Griboldo)	1	0,42	0	0,00	1	0,09
Polistes actaeon Haliday	1	0,42	0	0,00	1	0,09
Polistes billardieri (Fabricius)	3	1,27	0	0,00	3	0,27
Polistes cinerascens (de Saussure)	1	0,42	0	0,00	1	0,09
Polistes ferreri (de Saussure)	1	0,42	4	0,46	5	0,45
Polistes pacificus Fabricius	1	0,42	0	0,00	1	0,09
Polistes simillimus Zikán	19	8,05	0	0,00	19	1,71
Polistes subsericius (de Saussure)	3	1,27	0	0,00	3	0,27
Polistes versicolor (Olivier)	8	3,39	3	0,34	11	0,99
Polybia bifasciata de Saussure	5	2,12	46	5,26	51	4,59
Polybia bistriata (Fabricius)	5	2,12	32	3,66	37	3,33
Polybia chrysothorax (Lichtenstein)	2	0,85	7	0,80	9	0,81
Polybia fastidiosuscula (de Saussure)	8	3,39	92	10,53	100	9,01
Polybia ignobilis (Haliday)	5	2,12	3	0,34	8	0,72
Polybia jurinei de Saussure	1	0,42	3	0,34	4	0,36

Polybia minarum (Ducke)	1	0,42	25	2,86	26	2,34
Polybia occidentalis (Olivier)	12	5,08	19	2,17	31	2,79
Polybia paulista (R. Von. Ihering)	1	0,42	0	0,00	1	0,09
Polybia platycephala (Richards)	1	0,42	11	1,26	12	1,08
Polybia punctata du Buysson	2	0,85	35	4,00	37	3,33
Polybia quadrincicta de Saussure	2	0,85	0	0,00	2	0,18
Polybia scutellaris (White)	14	5,93	0	0,00	14	1,26
Polybia sericea (Olivier)	1	0,42	0	0,00	1	0,09
Protonectarina sylveirae (de Saussure)	6	2,54	5	0,57	11	0,99
Protopobybia sedula (de Saussure)	22	9,32	0	0,00	22	1,98
Synoeca cyanea (Fabricius)	4	1,69	4	0,46	8	0,72
Individual totals	**236**		**874**		**1110**	
Species richness (S`)	**40**		**23**		**40**	
Shannon-Wiener Index (H`)	**2,871**		**1,956**		**2,495**	
Berger-Parker Index (Dpb)	**0,2881**		**0,4016**		**0,3171**	

A high dominance of only few species was observed. *Agelaia vicina* de Sausurre and *Agelaia multipicta* (Haliday) were the most frequent species when considering only the attractive traps (40,16% and 23,0%, respectively). Some species of *Agelaia* are necrophagous, and were captured with the sardine stock in the present study, which may be used as an additional proteic resource offered to the larvae (Souza & Prezoto, 2006). Also, they may establish colonies with up to one million adults (Zucchi et al., 1995), which provides an enhanced foraging capacity and, consequently, better chances for one to capture specimens of *Agelaia* (Hunt et al., 2001). A high abundance of this taxon have already been reported in several studies in Brazil (Gomes & Noll, 2009; Arab et al., 2010; Jacques et al., 2012; Grandinete & Noll, 2013; Locher et al., 2014; Togni et al., 2014; Jacques et al., 2015).

Table 2. Polistinae richness comparison among different studies carried out in Brazil.

Authors	Species richness
Silveira, 2002 (Amazon)	79
Silva & Silveira, 2009 (Amazon)	65
Somavilla et al., 2014 (Amazon)	58
Somavilla et al., 2015 (Amazon)	49
Present Study	40
Souza et al., 2014a (Cerrado)	38
Souza & Prezoto, 2006 (Cerrado and Semidecidual Forest)	38
Souza et al., 2010 (Riparian Forest)	36
Brunismann et al., 2016 (Semidecidual Forest)	35
Souza et al., 2015 (Semidecidual Forest)	34
Simões et al., 2012 (Cerrado)	32
Locher et al., 2014 (Riparian Forest)	31
Jacques et al., 2015 (Agroecosystem)	29
Elpino-Campos et al., 2007 (Cerrado)	29
Souza et al., 2014b (Riparian Forest)	28
Jacques et al., 2012 (Anthropized Environment)	26
Prezoto & Clemente, 2010 (Rock Field)	23
Grandinete & Noll, 2013 (Cerrado)	22
Togni et al., 2014 (Atlantic Forest)	21
Santos et al., 2009 (Cerrado)	19
Bonfim & Antonialli Junior, 2012 (Riparian Forest)	18
Santos et al., 2007 (Atlantic Forest)	18
Oliveira et al., 2017 (Anthropized Environment)	18
Santos et al., 2007 (Restinga)	16
Silva-Pereira & Santos, 2006 (Rock Fields)	11
Elisei et al., 2017 (Caatinga)	10
Arab et al., 2010 (Atlantic Forest)	10
Santos et al., 2007 (Mangrove)	8
Gomes & Noll, 2009 (Semidecidual Forest)	7

Another species that was frequently trapped was *Polybia fastidiosuscula* Saussure, with 10,53% of relative frequency. Since the traps were placed inside Atlantic Forest fragments, the occurrence of this taxon may indicate a good conservation status of this area (Souza et al., 2010). Despite occurring in different biomas and altitudes (Souza et al., 2010, Albuquerque et al., 2015), *P. fastidiosuscula* is particularly dominant above 1500 meters high (Souza et al., 2015).

Mischocyttarus cassununga (R. Von. Ihering) was the most sampled species by actively searching for these insects. It is a highly sinathropic taxon easily found nesting in human buildings (Jacques et al., 2012; Oliveira et al., 2017). This nesting behavior may have been adopted to avoid competition for resources with other social wasps, for an anthropized environment that harbor various crops may offer a considerable amount of prey itens (Prezoto et al., 2007).

The species accumulation discovery depicted in Fig 2 (S_{obs} = 40) shows that the species curve tends to an asymptote. Also, the estimated number of species (Bootstrap 1 – 44,21) lies inside the confidence interval of 95%, showing that our sampling effort was sufficient. Despite the fact that the monthly active collecting effort may be considered low (ten hours per month), sampling throughout an entire year yelded results that may be considered a good approximation of the real biotic diversity within the study area (Barbosa et al., 2016).

All species captured by attractive traps were also sampled through active search (compare Table 1 and Table 3), highlighting the efficiency of this method. It is by far the most widely used sampling method to survey social wasps and the one with the higher sampling success regarding exclusive species (a species recorded by only one method) (Barbosa et al., 2016; Maciel et al., 2016), with a total of 17 exclusive species sampled herein. Although, the use of other methodologies may reveal sampling success of exclusive species as well, for some have been exclusively recorded by other methods such as attractive traps (e.g. Souza & Prezoto, 2006; Elpino-Campos et al., 2007; Jacques et al., 2012; Loucher et al., 2014; Souza et al., 2014b; Jacques et al., 2015). Also, important ecological and phenological information may be gathered by using different approaches to access community structure.

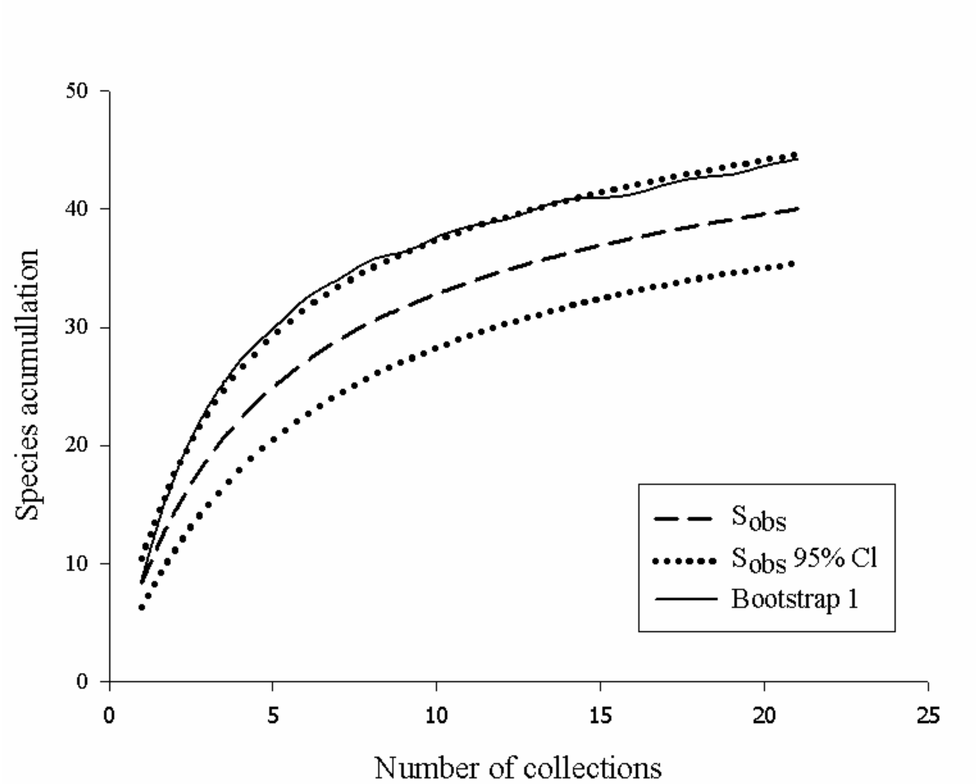

Fig. 2. Species accumulation curve for social wasps collected at Federal University of Lavras, Lavras, Minas Gerais, Brazil using the observed species richness within a 95% confidence interval and the estimated species richness (Bootstrap 1).

Table 3. Richness, diversity and dominance of social wasp species collected with different attractive baits at *Universidade Federal de Lavras*, Lavras, Minas Gerais, Brazil.

Taxon	**Honey**		**Molasse**		**Sardine**		**Passion Fruit Juice**	
	Nº of ind.	Frequency (%)	Nº of ind.	Frequency (%)	Nº of ind.	Frequency (%)	Nº of ind.	Frequency (%)
Agelaia multipicta (Haliday)	43	18.30	57	16.86	85	42.08	16	16.16
Agelaia vicina de Saussure	73	31.06	130	38.46	109	53.96	39	39.39
Apoica pallens (Fabricius)	4	1.70	5	1.48	0	0.00	0	0.00
Brachygastra lecheguana (Latreille)	0	0.00	3	0.89	0	0.00	0	0.00
Mischocyttarus ignotus Zikán	1	0.43	3	0.89	0	0.00	0	0.00
Mischocyttarus cassununga (R. Von. Ihering)	1	0.43	2	0.59	0	0.00	0	0.00
Mischocyttarus drewseni de Sausurre	2	0.85	3	0.89	0	0.00	0	0.00
Mischocyttarus labiatus Fabricius	0	0.00	6	1.78	0	0.00	0	0.00
Mischocyttarus socialis (de Saussure)	1	0.43	1	0.30	0	0.00	1	1.01

Polistes ferreri (de Saussure)	2	0.85	2	0.59	0	0.00	0	0.00
Polistes versicolor (Olivier)	1	0.43	2	0.59	0	0.00	0	0.00
Polybia bifasciata de Saussure	22	9.36	18	5.33	0	0.00	6	6.06
Polybia bistriata (Fabricius)	12	5.11	12	3.55	2	0.99	6	6.06
Polybia chrysothorax (Lichtenstein)	5	2.13	2	0.59	0	0.00	0	0.00
Polybia fastidiosuscula (de Saussure)	27	11.49	48	14.20	2	0.99	15	15.15
Polybia ignobilis (Haliday)	1	0.43	1	0.30	0	0.00	1	1.01
Polybia jurinei de Saussure	0	0.00	0	0.00	0	0.00	3	3.03
Polybia minarum (Ducke)	10	4.26	10	2.96	3	1.49	2	2.02
Polybia occidentalis (Olivier)	8	3.40	9	2.66	0	0.00	2	2.02
Polybia platycephala (Richards)	4	1.70	5	1.48	0	0.00	2	2.02
Polybia punctata du Buysson	16	6.81	16	4.73	1	0.50	2	2.02
Protonectarina sylveirae (de Saussure)	1	0.43	0	0.00	0	0.00	4	4.04
Synoeca cyanea (Fabricius)	1	0.43	3	0.89	0	0.00	0	0.00
Individual totals	**235**		**338**		**202**		**99**	
Species richness (S`)	**20**		**21**		**6**		**13**	
Shannon-Wiener Index (H`)	**2.193**		**2.084**		**0.8773**		**1.931**	
Berger-Parker Index (Dpb)	**0.3106**		**0.3846**		**0.5396**		**0.3939**	

Several kinds of attractive baits have been used to access social wasp species richness, such as natural and industrialized fruit juices (passion fruit, orange, guava, mango, pineapple), honey and sardine stock (Barbosa et al., 2016; Maciel et al., 2016). This bait diversity may be a result of the lack of studies testing the efficiency of each of these attractives, which may vary depending on the environmental conditions as well (Souza et al., 2012; Souza et al., 2015). In the present study, species abundance recovered by the four baits and by active search were consistently different, demonstrating that active search was the most effective collecting method, followed by molasse, honey, sardine and passion fruit juice (Table 4, Fig 3). Species richness also presented similar outcomes as ascribed for abundance (Table 5, Fig 4). Finally, Table 6 depicts contrast analyses comparing each collecting method in a pairwise way, revealing that only abundance retrieved by active search versus the use of molasse bait have not shown statistical differences. In all other cases (species abundance and richness), actively searching for social wasps was the most effective collecting methodology.

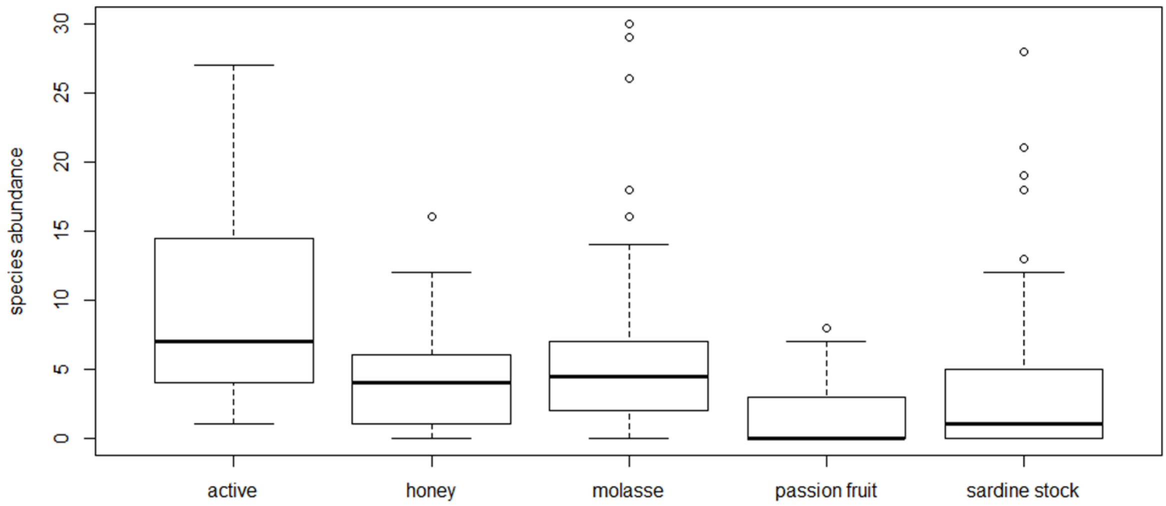

Fig 3. Species abundance attracted by different baits and active search.

Table 4. General linear mixed models on species abundance and different attractive baits and active search.

		Species abundance		
Fixed effect				
Coefficients	***Estimate***	***Std. Error***	***z-value***	***Pr(>|z|)***
(Intercept)	2.2878	0.1464	15.628	<0.001
Passionfruit	-1.8556	0.2594	-7.152	<0.001
Honey	-0.9793	0.2476	-3.955	<0.001
Molasse	-0.6162	0.2450	-2.515	<0.05
Sardine	-1.0880	0.2486	-4.376	<0.001
Random effects				
Group		***Variance***		***Std. Dev.***
Sampling date	(intercept)	0.2475		0.4975

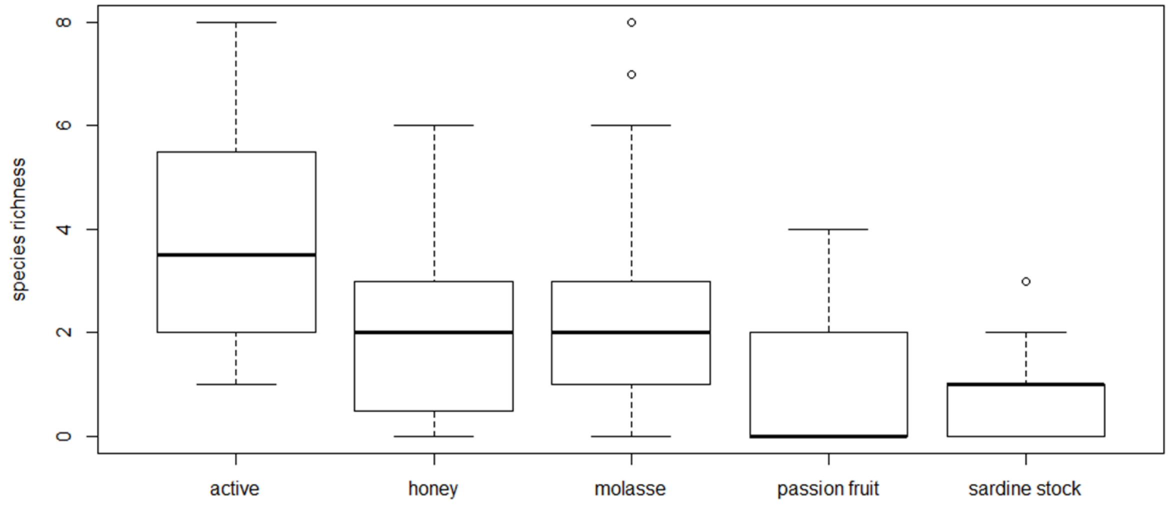

Fig. 3. Species richness attracted by different baits and active search.

Table 5. General linear mixed models on species richness and different attractive baits and active search.

		Species richness		
Fixed effect				
Coefficients	***Estimate***	***Std. Error***	***z-value***	***Pr(>|z|)***
(Intercept)	1.3443	0.1188	11.313	<0.001
Passionfruit	-1.6397	0.2187	-7.496	<0.001
Honey	-0.7325	0.1854	-3.951	<0.001
Molasse	-0.5640	0.1816	-3.106	<0.01
Sardine	-1.6397	0.2187	-7.496	<0.001
Random effects				
Group		***Variance***		***Std. Dev.***
Sampling date	(intercept)	0.07649		0.2766

Table 6. Abundance and species richness contrast analyses (Tukey test) among active search and baits.

Abundance	*p-value*	Richness	*p-value*
Active X Honey	<0.05	Active X Honey	<0.001
Active X Molasse	=0.58	Active X Molasse	<0.05
Active X Passion Fruit	<0.001	Active X Passion Fruit	<0.001
Active X Sardine	<0.01	Active X Sardine	<0.001
Honey X Molasse	=1.00	Honey X Molasse	=1.00
Honey X Passion Fruit	<0.01	Honey X Passion Fruit	<0.001
Honey X Sardine	=1.00	Honey X Sardine	<0.001
Molasse X Passion Fruit	<0.001	Molasse X Passion Fruit	<0.001
Molasse X Sardine	=0.183	Molasse X Sardine	<0.001
Passion Fruit X Sardine	<0.05	Passion Fruit X Sardine	=1.00

Sugar cane molasse is still a poorly explored attratctive bait in studies surveying polistine wasps (Jacques et al., 2015), but as shown above, was the most effective regarding species composition with 21 out of 23 taxa collected by traps. On the other hand, passion fruit juice traps captured only 13 species, with only one being exclusive to this attractive. Sardine stock is a widely used attractive, with 71% os the studies conducted in the state of Minas Gerais making use of this product (Maciel et al., 2016). However, almost all abundance and species richness captured by this attractive belong to only two species, *A. multipicta* and *A. vicina*, since these exhibit necrophagous habits (Souza & Prezoto, 2006). Finally, when monetary values are compared, sugar cane molasse is a cheaper product when compared to honey, for example, which allied to its efficiency in the capture of social wasps makes it an ideal attractive bait for studies of this nature.

Surveying organisms that may be influenced by anthropogenic activity provides the most valuable information when indicating priority areas for conservation. Furthermore, when these organisms are easily accessible and sampled in a fast and efficient way, studies may be conducted within a reasonable amount of time. This is the case of Neotropical social wasps. It is clear by our results that actively searching for polistines is far superior than using attractive baits: two collectors spent a total of 140 hours in the field, while traps remained in the field for a total of 1176 hours (summing up all trap hours individually). All our analyses recovered active searching for wasps as the best method regarding species richness and abundance, despite using a somewhat more efficient and affordable attratctive bait (sugar cane molasse).

Another factor that may affect our understanding of the real efficiency of attratctive traps is that most studies conducted in Brazil make use of different kinds of baits (Maciel et al., 2016). Also, field hours differ abruptly among analyzed studies. Since no real statististical comparison among baits and field hours used in different studies may be accomplished, active searching for Neotropical social wasps remains as the best surveying method for this group of organisms, as indicated by Silveira (2002).

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ARTIGO 3 - NICHE OVERLAP AND DAILY PATTERN ACTIVITY OF SOCIAL WASPS (VESPIDAE: POLISTINAE) IN KALE CROPS

Artigo Aceito para publicação no periódico *Sociobiology.*

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Abstract

Kale (*Brassica oleraceae* var. *acephala*) is of great importance in human nutrition and local agricultural economies, but its growth is impaired by the attack of several insect pests. Social wasps prey on these pests, but few studies report the importance of this predation or the potential use of wasps as biological control for agricultural pests. This study aimed to survey the species of social wasps that forage in kale (*B. oleraceae* var. *acephala*), recording the influence of temperature and time of day on the foraging behavior of these wasps. The research was conducted at the Federal Institute of Education, Science and Technology of Minas Gerais - Bambuí Campus, from July to December 2015, when twelve collections of social wasps that foraged on a common area of kale cultivation were made, noting the temperature and time of collection for each wasp. *Polybia ignobilis*, *Protonectarina sylveirae* and *Protopolybia sedula* were the most common wasp species foraging in fields of kale. Interspecific interactions between wasp species did not affect their coexistence within kale fields, with peak foraging occurring between 1000 and 1100 hours. Social wasps are important predators of herbivorous insects in the agricultural environment and the coexistence of a great diversity of these predators can help control pest insects that occur in the crop. Moreover, knowing factors that influence foraging behaviors of common wasp species that occur in this crop is important for effective use of these insects in the biological control of pests.

Keywords: Biological control, foraging, Polistinae.

Introduction

Insects from the Vespidae family, order Hymenoptera, popularly known by wasps, include species with solitary or eusocial habits. Social wasps comprise three subfamilies (Stenogastrinae, Polistinae and Vespinae) (Carpenter & Marques, 2001). Wasps from the subfamily Polistinae are the only social species that occur in Brazil and belong to three tribes, Polistini, Mischocyttarini and Epiponini, representing 21 genera and 343 species (Hermes et al., 2017).

Social wasps forage to find water for nests and cooling, for plant fibers for nest materials, and for carbohydrates, such as pollen and nectar, for adult and larval nutrition (Raveret-Richter, 2000; Lima & Prezoto, 2003; Clemente et al., 2017). In addition, they forage for animal protein, especially insects from the orders Diptera, Hemiptera, Hymenoptera, and Lepidoptera, which comprise about 90-95% of captured prey (Prezoto et al., 2005; Bichara-Filho et al., 2009). These prey are torn, macerated and fed to larvae, being the main source of protein for social wasps in their early stages of development (Rabb & Lawson, 1957; Jeanne et al., 1995; Gomes et al., 2007). Nutrients, carbohydrates and proteins, can be stored inside the cells for later consumption, constituting a reserve for unfavorable periods (Barbosa et al., 2017; Michelutti et al., 2017).

Foraging activity is one of the most important and complex behaviors exhibited by social wasps (Lima & Prezoto, 2003) and depends on the insects' ability to interact with the environment, as well as the availability of essential resources to support the colony (Gomes et al., 2007). These wasps, like other generalists, forage predominantly on the most abundant resource, without preference or selective behavior (Raveret-Ritcher, 2000; Santos et al., 2007). However, these wasps may return to hunt in locations of previous successful predation activity and feed several times on the same prey species, with individuals acting as facultative specialists (Raveret-Richter, 2000; Bichara-Filho et al., 2009). In general, higher temperatures, higher light intensity, lower humidity and lower wind speed are favor foraging conditions (Lima & Prezoto, 2003; Ribeiro-Junior et al., 2006).

Kale (*Brassica oleraceae* var. *acephala*) belongs to the Brassica family, which has the most oleaceous species, totaling 14 vegetables (Filgueira, 2008), and is of great importance to human nutrition, as they exhibit good adaptation to a variety of climates (Filgueira, 2008). Several species of insect pests attack kale, such as the whitefly, *Bemisia tabaci* (Genn.) (Hemiptera: Aleyrodidae), and the aphids *Brevicoryne brassicae* (L.) and *Myzus persicae*

Sulzer (Hemiptera: Aphididae) (Galo et al., 2002). These insects weaken plants by sucking sap and introducing toxins into their vascular system, causing leaf tissue deformations and gall formation, as well as contributing to the appearance of sooty mold on the foliage through honeydew excretion (Galo et al., 2002; Van Emden, 2013).

Several Lepidoptera also attack kale crops, such as the black cutworm *Agrotis ipsilon* (Hufnagel) (Noctuidae), the cabbage looper *Trichoplusia ni* (Hübner) (Noctuidae), the cabbage caterpillar *Ascia monuste orseis* (Godart) (Pieridae) and the diamondback moth *Plutella xylostella* (L.) (Plutellidae) (Gallo et al., 2002). *A. monustes orseis* and *P. xylostella* constitutes key-pests of this crop in the Neotropical region, mainly in Brazil (Maranhão et al., 1998; Barros & Zucoloto, 1999). These species larvae feed on the leaves (Gallo et al., 2002), resulting in losses of up to 100% of crop production (Vendramim & Martins, 1982; Chen et al., 1996).

The control of kale pests is mainly carried out by the application of insecticides (Gallo et al., 2002; Andrei, 2013). These synthetic chemicals can lead to a number of problems, such as residues in food, the death of natural enemies, poisoning of the applicators, and the emergence of resistant pest populations. Therefore, the use of biological control agents could be an effective, cheap and safe alternative to the use of these toxic products.

Social wasps have been recorded preying on kale pests (Picanço et al., 2010), however few studies report the importance of this predation or potential for the use of wasps in the biological control of agricultural pests (Rabb & Lawson, 1957; Morimoto, 1961; Prezoto & Machado, 1999a,b; Freitas et al., 2015).

This research aimed to survey the species of social wasps that forage in kale (*B. oleraceae var. acephala*) crops, recording the influence of temperature and time of day on the foraging activity of these wasps and the temporal niche overlap of this community. With these data, we can identify which species have the greatest potential to be used in biological control programs for kale pests.

Material and Methods

This research was carried out at the Federal Institute of Education, Science and Technology of Minas Gerais - Bambuí Campus, from July to December 2015. The *campus* has a total area of 328 ha, being a human dominated but diverse landscape with a predominance of agricultural areas and buildings. A total of 175 ha are used for agricultural crops (corn, beans, sugarcane, orange, banana, coffee and vegetables) and pastures, and 34 ha are occupied by buildings, most of them are close to the cultivars. The *campus* has a high diversity of social wasps, with 29 species and 8 genera (Jacques et al., 2015).

Twelve collections were carried out in a 5 x 10 m area of kale (*B. oleracea* var. *acephala*) (Adapted from Picanço et al., 2010) between the period from 0900 to 1500 hrs, in which the social wasps that were foraging on the crop were collected with an entomological net, placed in a bottle containing ethyl ether and preserved in 70% ethanol (adapted from Souza et al., 2013). The time and temperature of the day at the time of collection of each wasp were recorded throughout the experiment to be correlated with the foraging activity. Collection data were used to analyze the daily patterns of activity, diversity, dominance and temporal niche overlap of social wasp species.

The collected individuals were identified with entomological keys (Richards, 1978; Carpenter, 2004), and the diversity of species calculated via Shannon-Wiener diversity (H') and Berger-Parker dominance (Dpb) indices, using the program Past, v. 2.17c (Hammer et al., 2005).

Temporal niche overlap for each possible pair of wasp species was determined using the Schoener index (Schoener, 1986). The Kolmogorov-Smirnov test for two samples was used to evaluate the interspecific differences between activity patterns for each pair of species (Siegel, 1956). Temporal niche overlap was calculated only for species of social wasps represented in the samples by more than eight specimens to minimize the effect of low abundance on the essay.

The results of the regression analysis were performed for the foraging frequency of the wasps, taking into account the variables "air temperature" and "time of day" with $p < 0.05$ (Picanço et al., 2010). For all species, it was considered the linear regression model or the model with quadratic effects. The selection of the best model was performed based on the determination coefficient. The assumptions of the model were verified through graphical analysis and through the Shapiro-Wilk, Durbin-Watson and White tests to verify error normality, residual autocorrelation and variance heterogeneity, respectively. All analyzes were conducted in the 3.3.1 version of R software (R Core Team, 2017). For the Durbin-Watson test, the *lmtest* package was used (Zeileis & Hothorn, 2002).

Results and Discussion

Three hundred and fifty-eight specimens belonging to six genera and 16 species of social wasps were collected in kale crops with a Shannon-Weiner diversity of H '= 1.84 (Table 1). The species diversity was similar to visitation in cherry trees (*Eugenia uniflora* Linnaeus) (Souza et al., 2013) and higher than other studies which analyzed only one species of plant (De Souza et al., 2010; Santos & Presley, 2010; De Souza et al., 2011; Barbosa et al., 2014).

Social wasps flew over the crop and explored the kale plants, especially those with damaged leaves. This foraging behavior may be related to the presence of *A. monustes orseis*, *B. brassicae* and *B. tabaci* in kale plants. These pests belong to the orders of insects that are most captured by the social wasps (Prezoto et al., 2005; Bichara-Filho et al., 2009; Freitas et al., 2015). The presence of leaves damaged by herbivores in herbaceous plants attracted *Polybia occidentalis* (Olivier), *Polybia diguetana* Buysson and *Polybia fastidiosuscula* Saussure (Saraiva et al., 2017). Tobacco plants previously damaged by *Manduca sexta* (L.) (Lepidoptera: Sphingidae) and *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae) attracted more foraging individuals from *Mischocyttarus flavitarsis* (de Saussure) than non-damaged plants (Cornelius, 1993).

Assumptions of error normality, autocorrelation and variance heterogeneity were met in all adjusted models, considering the graphical analysis and the appropriate usage of the tests (results not shown).

The foraging behavior of the social wasps was related to the time of day ($p = 0.025$) with the maximum number of wasps collected between 1000 and 1100 hours (Fig 1). Results similar to those found in cashew trees (*Anacardium occidentale* L.) (Anacardiaceae), with greater foraging between 0900 and 1200 hrs (Santos & Presley, 2010). The air temperature directly affects foraging behavior of social wasps (Santos et al., 2009; De Castro et al., 2011), with foraging occurring mainly during warmer times of day (Picanço et al., 2010; Barbosa et al., 2014), however air temperature was not an effective predictor of wasp activity ($p = 0.2184$). Other factors not analyzed, such as the amount of light, wind speed and humidity, also affect foraging behavior (Santos et al., 2009; De Castro et al., 2011).

Table 1. Number of individuals, species richness (S'), Shannon-Wiener index (H') and Berger-Parker dominance (Dpb) of the collected social wasps, per hour, in twelve collections made in kale (*B. oleracea var. acephala*) at the Federal Institute of Education, Science and Technology of Minas Gerais (IFMG), Bambuí *Campus*, Minas Gerais.

Species	**09:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**Total**
1. *Brachygastra lecheguana* (Latreille, 1824)	3	4	1	2	1	-	-	11
2. *Mischocyttarus drewseni* (Saussure, 1857)	1	1	-	2	2	1	1	8
3. *Mischocyttarus labiatus* (Fabricius, 1804)	-	-	1	-	-	-	-	1
4. *Mischocyttarus latior* (Fox, 1898)	-	-	-	1	-	1	-	2
5. *Polistes ferreri* (Saussure, 1853)	-	-	-	1	-	-	-	1
6. *Polistes simillimus* (Zikán,1951)	-	1	1	-	-	-	-	2
7. *Polistes versicolor* (Olivier, 1971)	-	-	3	1	1	3	1	9
8. *Polistes satan* (Bequaert, 1940)	1	1	2	4	3	1	-	12
9. *Polybia fastidiosuscula* (Saussure, 1854)	-	1	-	-	-	-	-	1
10. *Polybia ignobilis* (Haliday, 1836)	28	29	22	23	21	19	5	147
11. *Polybia jurinei* (Saussure, 1854)	-	-	1	-	1	-	-	2
12. *Polybia occidentalis* (Olivier, 1971)	-	5	1	2	6	1	-	15
13. *Polybia paulista* (R. Von. Ihering, 1896)	2	7	4	3	4	2	-	22
14. *Polybia sericea* (Olivier, 1971)	-	2	2	-	-	-	-	4
15. *Protonectarina sylveirae* (Saussure, 1854)	16	17	13	13	11	8	2	80
16. *Protopolybia sedula* (Saussure, 1854)	8	4	4	4	7	11	3	41
Number of individuals	**59**	**72**	**55**	**56**	**57**	**47**	**12**	**358**
Species richness (S')	**7**	**11**	**12**	**11**	**10**	**9**	**5**	**16**
Shannon-Wiener index (H')	**1,35**	**1,78**	**1,85**	**1,81**	**1,88**	**1,58**	**1,59**	**1,84**
Berger-Parker dominance (Dpb)	**0,48**	**0,40**	**0,40**	**0,41**	**0,36**	**0,41**	**0,38**	**0,41**

There was high dominance (Dbp = 0.41), with *Polybia ignobilis* (Haliday) (N= 147), *Protonectarina sylveirae* (Saussure) (N= 80) and *Protopolybia sedula* (Saussure) (N= 41) representing 75% of the total sampled individuals. The other most frequently collected species were *Polybia paulista* (R. von Ihering) (N= 22), *P. occidentalis* (N= 15), *Polistes satan* (Bequaert) (N= 12), *Brachygastra lecheguana* (N= 11), *Polistes versicolor* (Olivier) (N= 9), *Mischocyttarus drewseni* (Saussure) (N= 8), and *Polybia sericea* (Olivier) (N= 4). *Mischocyttarus latior* (Fox), *Polistes simillimus* (Zikán) and *Polybia jurinei* (Saussure) (N= 2) and *Mischocyttarus labiatus* (Fabricius), *Polistes ferreri* (Saussure) and *Polybia fastidiosuscula* (Saussure) (N= 1) were uncommon and considered of accidental occurrences.

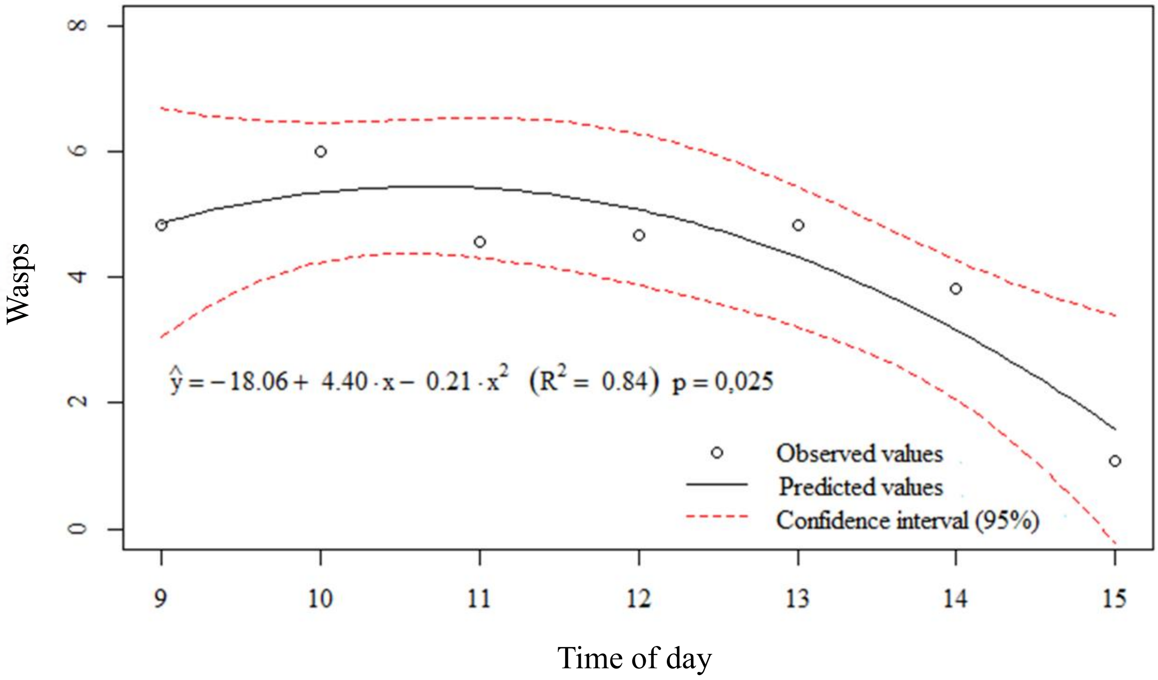

Fig. 1. Effect of time of day on average number of social wasps foraging in kale (*Brassica oleraceae* var. *acephala*) from July to November 2016, in Bambuí, MG.

Polybia ignobilis is the main predator of *A. monustes orseis* (Picanço et al., 2010), and the predation of this wasp on the cabbage caterpillars was recorded (Fig 2). Thus, the presence of this pest may have stimulated the greater presence of *P. ignobilis* in the crop. Social wasp workers forage alone and opportunistically (Jeanne et al., 1995; Michelutti et al., 2017), being able to return to hunt in locations of previously successful hunts and feeding several times of the same species of prey (Raveret -Richter, 2000; Bichara-Filho et al., 2009). To optimize this form of foraging, signals can be exchanged among workers to facilitate the acquisition of resources for the colony (Taylor et al., 2011). This behavior was reported in colonies of *P. occidentalis* (Hrncir et al., 2007; Schueller et al., 2010).

Fig. 2. Social wasp *Polybia ignobilis* (Hymenoptera: Vespidae) preying on *Ascia monuste orseis* (Lepidoptera: Pieridae) on a kale plant (*Brassica oleracea* var. *acephala*).

Species of the genus *Polybia* (Lepeletier) are also dominant in cashew, mango (*Mangifera indica* L.) and cherry trees (Santos & Presley, 2010; Souza et al., 2013; Barbosa et al., 2014). Wasps of this genus form large colonies, founded by a swarm composed of dozens of queens and hundreds of workers, which makes their local abundance greater than that of species whose colonies can be founded by one or a few wasps (Barbosa et al., 2014).

The highest number of *P. ignobilis* was found at 0930 h, using a quadratic model for time of day (Fig 3A), different from that observed in the same crop in Viçosa/MG, where the highest foraging occurred at 1330 h (Picanço et al., 2010). Through a linear model for the air temperature it was observed that the amount of *P. ignobilis* individuals tended to decrease with increasing temperature (Fig 3B). In Viçosa/MG the result was similar, with the number of individuals increasing up to 29ºC, and decreasing after this temperature (Picanço et al., 2010). Time of day was a better predictor than temperature and accounted for 87% of ther variation in mean *P. Ignobilis* abundance (Fig. 3). Higher temperatures occur after the period of greatest foraging, 0930 h, thus we find a smaller number of individuals after this time of day. In the period of higher temperatures, the wasps are concentrated in the collection of water to cool the colony (Akre, 1982; Montefusco et al., 2017).

The quadratic model for time of day explained 96% of the variation in mean *P. sylveirae* captures, with peak abundance observed early in the day (0900 hr) (Fig. 4).This time is different from the time found for all species, which was between 1000 and 1100 hrs. Temperature did not affect *P. sylveirae* abundance. The presence of *A. monustes orseis* may attract *P. sylveirae*, as this is a common prey species of *P. sylveirae* (Bueno & Souza, 1993). In addition, this species preys on Hemiptera such as *Aleurothrixus floccous* (Maskell) (Hemiptera: Aleyrodidae) (Souza & Zanuncio, 2012), probably being attracted by the presence of *B. brassicae* and *B. tabaci*.

None of the statistic models fit the data considering the time of day for *P. sedula*. In contrast, observations of colonies of this species indicate that peak foraging activity occurs between 1030 and 1430 (Detoni et al., 2015). For the air temperature, the quadratic regression model was selected, in which the minimum number of wasps was obtained around 29º C (Fig 5). The climatic variables possibly have a low effect over the foraging rhythm of this wasp (Detoni et al., 2015). The presence of an envelope that protects *P. sedula* nests can generate a certain level of homogenization of the internal environment in terms of temperature and humidity, increasing the importance of internal colony stimuli when it comes to foraging outflows (Detoni et al., 2015). Moreover, this research recorded the foraging behavior only in kale, and this species may be foraging in another plant species. This species preys on *A. floccous* (Souza & Zanuncio, 2012) and probably is also attracted by the presence of *B. brassicae* and *B. tabaci*.

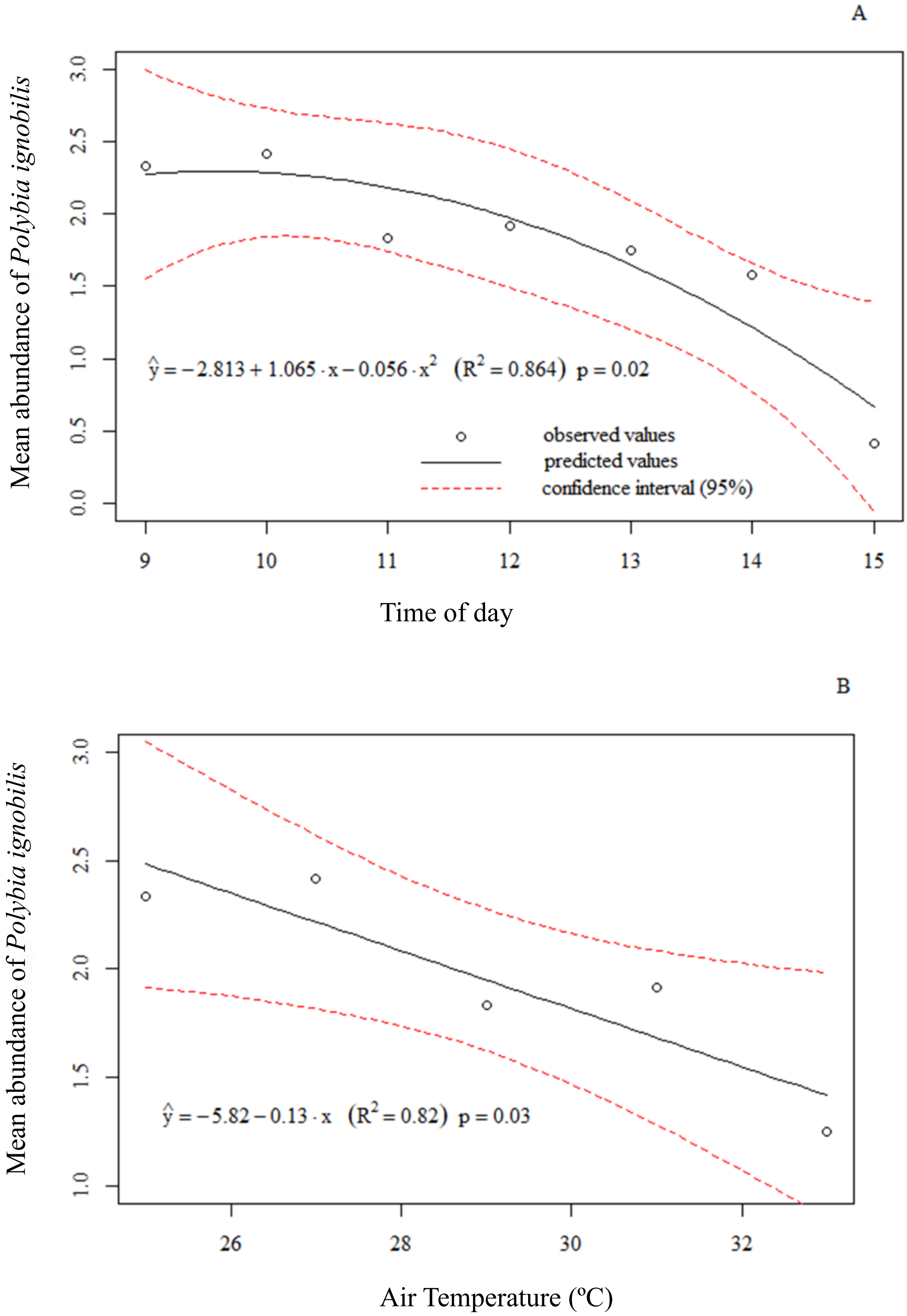

Fig. 3. Average number of wasps of *Polybia ignobilis* (Hymenoptera: Vespidae) foraging in kale plants (*Brassica oleracea* var. *acephala*) as a function of: A - time of day and; B - air temperature, from July to November 2016 in Bambuí, MG.

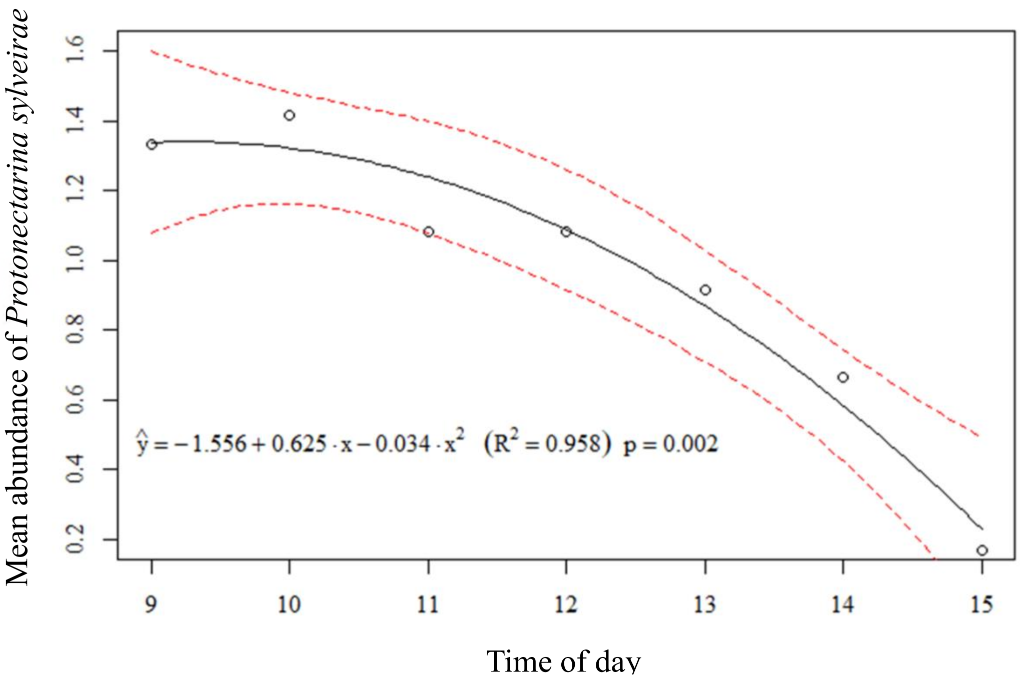

Fig. 4. Effect of time of day on average number of wasps of *Protonectarina sylveirae* (Hymenoptera: Vespidae) species foraging in kale plants (*Brassica oleracea* var. *acephala*) from July to November 2016 in Bambuí, MG.

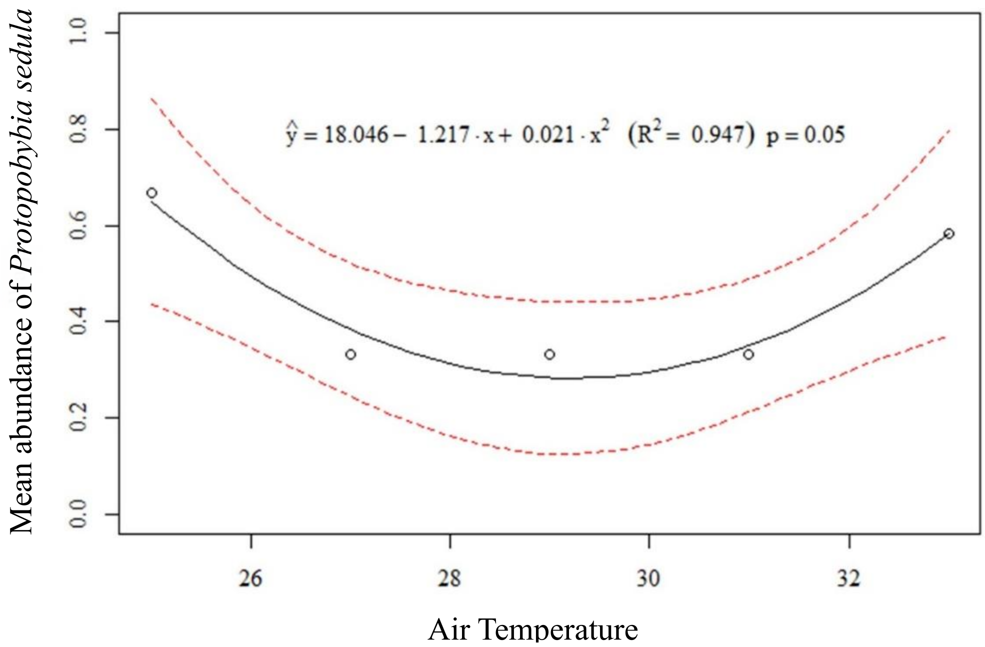

Fig. 5. Effect of air temperature on average number of wasps of *Protopobybia sedula* (Hymenoptera: Vespidae) species foraging in kale plants (*Brassica oleraceae* var. *acephala*) from July to November 2016 in Bambuí, MG.

The temporal niche overlap between pairs of species of social wasps varied between 0.31- 0.96 (Schoener index) (Table 2), being smaller between *B. lecheguana* and *P. versicolor* and higher between *P. ignobilis* and *P. sylveirae*. In general, the activity overlap was relatively high, being greater than 50% in 31 of the 36 pairs, and there was no significant difference based on Kolmogorov-Smirnov 2-sample tests. This high value of temporal niche overlap was also found in *A. occidentale* and *E. uniflora* (Santos & Presley, 2010; Souza et al., 2013), suggesting a trend of coexistence among species of this group. The agricultural features of the campus, with the presence of many crops, and consequently many herbivores, may have led to a decrease in interspecific competition allowing greater coexistence of wasps in the crop. The division of resources by guild members and the resulting competitive structure can only be seen if they are maintained over time by competition for limiting resources (Pianka, 1980). Moreover, the generalist tendencies of social wasps allows them to have low dependence on particular food resources (Santos et al., 2007). This dietary flexibility likely facilitates co-existence by reducing interspecific competition.

We recorded 4 species, *M. labiatus*, *P. ferreri*, *P. fastidiosuscula* and *P. sylveirae* that had not been collected previously at the IFMG - Bambuí *Campus* according to a diversity survey of social wasps previously performed by Jacques et al. (2015).

Wasp species exhibited similar temporal activity patterns in a small patch of kale, suggesting that interspecific interactions among these species did not affect their ability to coexistence as predators on pest species. Social wasps are important predators of herbivorous insects in the agricultural environment and the coexistence of a great diversity of these can lead to a greater control of the pest insects that occur on the crop. Furthermore, knowing the period and the factors that influence the foraging of the main species that occur in the crop is important for the effective use of these insects in the biological control of pests.

Table 2. Temporal niche overlap (Schoener index) among pairs of species of social wasps (species with more than eight individuals) collected in kale (*B. oleracea var. acephala*) crops at the Federal Institute of Education, Science and Technology of Minas Gerais (IFMG), Bambuí *Campus*, Minas Gerais. Significance (P≤0.05) for the Kolmogorov-Smirnov test for two samples used to evaluate differences between the patterns of temporal activity among pairs of species of social wasps is indicated above the diagonal.

	Br. le.	***Mi. dr.***	***Po. ve.***	***Po. sa.***	***Po. ig.***	***Po. oc.***	***Po. pa.***	***Pr. sy.***	***Pr. se.***
Brachygastra lecheguana	-	NS	NS	NS	NS	NS	NS	NS	NS
Mischocyttarus drewseni	0,61	-	NS	NS	NS	NS	NS	NS	NS
Polistes versicolor	0,31	0,46	-	NS	NS	NS	NS	NS	NS
Polistes satan	0,62	0,75	0,47	-	NS	NS	NS	NS	NS
Polybia ignobilis	0,77	0,71	0,54	0,70	-	NS	NS	NS	NS
Polybia occidentalis	0,72	0,58	0,36	0,60	0,61	-	NS	NS	NS
Polybia paulista	0,82	0,63	0,49	0,73	0,81	0,77	-	NS	NS
Protonectarina sylveirae	0,79	0,68	0,51	0,71	0,96	0,62	0,83	-	NS
Protopolybia sedula	0,64	0,69	0,65	0,62	0,79	0,50	0,65	0,75	-

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ARTIGO 4 - THE USE OF *POLISTES VERSICOLOR* IN THE CONTROL OF *Ascia monuste orseis* IN KALE CULTIVATION

Artigo Submetido à Pesquisa Agropecuária Brasileira.

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Abstract

Social wasps have been successfully utilized as means of biological control, particularly for the larvae of Lepidoptera. *Ascia monuste orseis* causes devastating effects on the kale, inducing production losses of up to 100% and therefore requiring stringent control measures. This work aimed at testing the species *Polistes versicolor* as a potential means of biological control of *A. monuste orseis*, during autumn and winter, when the kale crop shows good development. These experiments were conducted at the IFMG - Bambuí Campus, between May and June 2017, during which time four *P. versicolor* colonies were translocated to artificial shelters constructed in proximity to the kale crop, being registered daily the predation of the social wasp on like of *A. monuste orseis* caterpillars. The translocation of the *P. versicolor* colonies onto the kale crop during the cold and drought seasons was shown to be ineffective in controlling the *A. monuste orseis* population. This was because this social wasp exhibited low foraging activity, and therefore a low degree of predation on the target pest; however, it became crucial to assess their activity during the hottest and most humid times of the year, as *P. versicolor* effectively preys upon the various species among the Lepidoptera.

Index terms: *Brassica oleracea*, biological control, lepidoptera, social wasps.

Uso de *Polistes versicolor* no controle de *Ascia monuste orseis* em cultivo de couve-comum

Resumo

Vespas sociais são utilizadas de forma efetiva no controle biológico, principalmente de larvas de Lepidoptera. *Ascia monuste orseis* pode ocasionar prejuízos de até 100% na produção, necessitando de formas de controle deste inseto. Portando, o objetivo deste trabalho é testar a espécie *Polistes versicolor* para o controle biológico de *A. monuste orseis*, no outono e inverno, período de melhor desenvolvimento da couve-comum. O presente trabalho foi realizado no IFMG - *Campus* Bambuí, no período de maio a junho de 2017, onde quatro colônias de *P. versicolor* foram trasnlocadas para abrigos artificiais próximos a cultura da couve-comum, sendo registrado diariamente a predação da vespa social sobre as lagartas de *A. monuste orseis*. A translocação de colônias de *P. versicolor* para a cultura da couve, em períodos de frio e estiagem, não foi efetivo para o controle da população de *A. monuste orseis,* devido à baixa atividade de forrageio desta vespa social, e consequentemente, baixa predação sobre a praga alvo, entretanto, é necessário uma avaliação nos períodos mais quentes e úmidos do ano, pois *P. versicolor* preda de forma efetiva diferentes espécies de lepidópteros.

Termos para indexação: *Brassica oleracea*, biological control, lepidoptera, social wasps.

Introduction

The social wasps (Hymenoptera: Vespidae) are usually included among the subfamilies Polistinae, Stenogastrinae and Vespinae, of which Polistinae alone, comprising 343 species, is found in Brazil (Hermes et al, 2017).

Significant as natural predators of pest insects, these social wasps are effective even in small populations, and make substantial contributions towards controlling and reducing the peak times of infestation (Picanço et al, 2010). Lepidopteran larvae are among the preferred prey of social wasps (Prezoto & Machado, 1999; Bichara-Filho et al., 2009; Freitas et al., 2015). Some species of polistine wasps, particularly those of the genus *Polistes*, have already been employed in biological control programs in Brazil (Prezoto & Machado, 1999; Marques, 2005; Elisei et al., 2010).

Kale (*Brassica oleracea* var. *acephala*), which belongs to the family Brassicaceae, is the largest among the oyster species, and includes 14 vegetables. Besides the common cabbage, (*B. oleracea* var. *capitata*), the others are cauliflower (*B. oleracea var. botrytis*), broccoli (*B. oleracea* var. *italica*) and mustard (*B. juncea*) (Filgueira, 2000). The kale is nutritionally significant in the human diet and reveals better development during the autumn and winter; however, it expresses a high degree of adaptability to varied climates (Filgueira, 2000).

Ascia monuste orseis (Godart) (Lepidoptera: Pieridae), one of the key pests of crops in the Neotropical region, mainly in Brazil (Bittencourt-Rodrigues & Zucoloto, 2009). As the caterpillars of this species devour the leaves, they cause great cultivation losses, which translate sometimes into as much as 100% production loss (Vendramim & Martins, 1982).

Four or five days after the females of this pest oviposit the undersurface, most often, of the young leaves, (Bittencourt-Rodrigues & Zucoloto, 2009), the caterpillars hatch out. During the first and second instars they feed in the site where oviposition had occurred. However, the fourth and fifth instar caterpillars exhibit some degree of mobility and move to other leaves and sometimes even from one cultivar to another (Barros-Bellanda & Zucoloto, 2003). The larval period extends for 20 to 25 days, after which the pupal stage lasts for a mean of 11 days (Bittencourt-Rodrigues & Zucoloto, 2009).

Ascia monuste orseis is mostly controlled by insecticide application, which can result in several problems, such as remaining as residues in food, mortality of natural enemies, poisoning to the applicators, and development of resistant pest populations. Thus, the use of agents of biological control is one method of minimizing the employment of these products. However, only one study is available, demonstrating the effectiveness of the social wasp *Polybia ignobilis* (Haliday) in the biological control of this pest (Picanço et al., 2010), and to date there is no reliable data on the action of wasps belonging to genus *Polistes*.

The objective of this work, therefore, is to examine the effectiveness of the *P. versicolor* (Hymenoptera: Vespidae) found in the kale crop (*B. oleracea var. acephala*), on the biological control of *A. monuste orseis* (Godart) (Lepidoptera: Pieridae), during the autumn and winter seasons, the time when this brassica crop develops well.

Materials and Methods

From May to June 2017, all the experiments were performed at the Federal Institute of Minas Gerais, Bambuí Campus, Bambuí, Minas Gerais, Brazil, in a kole planting (*B. oleracea* var. *acephala*), and subjected to treatment with conventional cultivation practices (Filgueira, 2000), without the pesticide application.

The *P. versicolor* species in particular was selected as an agent of biological control for various reasons, as listed: a) availability of the predation records of this wasp on the lepidopteran caterpillars (Marques, 2005, Elisei et al., 2010); b) as the dominant species in the IFMG - Bambuí Campus (Jacques et al., 2015), which facilitates nest location; c) being a registered forage species on the kale culture (Jacques et al., article submitted); d) easy translocation of their nests (Elisei et al., 2012), which enables them to accept the shelter; and f) wide distribution of this species across Brazil (Richards, 1978), opening up opportunities to employ this methodology throughout the country.

The experiment included two treatments: T1 - Kale planting with the *P. versicolor* wasp colonies and *A. monuste orseis* caterpillar infestation; T2 - Kale being planted without the wasp colonies and *A. monuste orseis* caterpillar infestation. The second treatment was employed as a control, with which the mortality rate of the treatments with the wasp colonies and without them could be compared.

Each treatment was conducted in an area of 5 x 5 m, provided with 100 x 50 cm spacing (Filgueira, 2000), for a total of 5 rows containing 10 plants in each. The areas were 900 m apart, to ensure that the T1 treatment wasps did not consume the T2 treatment caterpillars. The longest return distance to the nest for the *P. versicolor* workers was established as 850 m (Gobbi, 1978).

In the T1 area, artificial wooden shelters, constructed using a 30x40x1 cm sized board and attached to a deck of 1.8 m, were installed. In each shelter, a 13x17x11 cm sized white plastic pot, open at the base alone, was installed, to offer protection against the rain and sun (Elisei et al., 2012). The base of each batten, up to a height of around 50 cm, was coated with burnt oil and grease, to protect against ant attacks (Prezoto & Machado, 1999). Four such shelters were constructed at about one-meter distance from the border of the crop.

Four *P. versicolor* colonies were identified and gathered from man-made constructions on campus, and using the translocation method proposed by Elisei et al. (2012) the colonies were captured during the early hours of the night, when most of the wasps are in the nest

(Prezoto & Machado, 1999). After carefully bagging the colonies in a large plastic bag without destroying their peduncles, the wasps were separated from the nest. The wasps showed positive phototropism, moving immediately to the highest and brightest portion of the bag, facilitating their separation from the nest. Then, the colonies were immediately glued to the shelters by their peduncles, using cyanoacrylate ester glue or Super-Bonder® (Figure 1). The plastic bag containing the individuals was wrapped in the overnight shelter of the translocation and removed the next morning after all the wasps had flown away from it.

Figure 1: The *Polistes versicolor* colony translocated to the artificial shelter.

Once the nests were translocated, 30 numbers of the third and fourth instar larvae of *A. monuste orseis* were released at 7 o'clock in the morning, on five randomly selected kale plants, for both treatments T1 and T2, for fifteen days. In this experiment five plants corresponded to 10% of the total number of plants, demonstrating the degree of economic loss to the crop (Picanço et al., 2005). At 18 hours of the same day, the caterpillars were collected, and the daily degree of predation was recorded for both treatments. As *P. versicolor* experiences a diurnal rhythm, the caterpillars were left undisturbed at night to minimize their death due to other factors. Daily observations were recorded between 11am and 1pm, (and feeding was *ad libitum*), to confirm the cause of death of the *A. monuste orseis* caterpillars,

The *A. monuste orseis* were produced by first collecting the postures in the IFMG-Bambuí garden. They were packed in 500 ml pots and brought to a B.O.D. with the temperature controlled at 25 ± 2 ºC and a 12 h photoperiod. Fresh kale leaves were supplied daily to the caterpillars, until they reached the pupal stage. The pupae were transferred to a cage (2.5 x 2.5 x 2.5 m) in a greenhouse having 20 pots with kale seedlings for oviposition. The adults were fed with 10% honey and the new postures collected every day.

A comparison was made of the daily mortality rate between the two treatments and the means were compared using the t test at the 5% level of significance through the statistical program Past, v. 2.17c (Hammer et al., 2005). The *P. versicolor* colonies were also closely tracked, and the number of individuals from the colonies was observed every day (Prezoto & Machado, 1999). The colonies were then removed from the T1, 15 days after the experiment commenced and the predation each day was noted for another 15 days to record the effect of the treatment site on the final findings.

The findings recorded of the daily mortality rate were subjected to regression analyses, accounting for the variables of "daily temperature" and "relative air humidity", with $p < 0.05$ using the BioEstat 5.3 program (Ayres et al., 2007). Relative temperatures and humidities were determined from the Bambuí weather station, situated on the IFMG-Bambuí Campus. Measurements were taken at nine and fifteen hours every day, and their means were utilized for the regression analyses.

Results and Discussion

Treatment T1, involving the *P. versicolor* colonies showed a value of 18.8% for the mean daily mortality rate of the *A. monuste orseis*. However, the T2 treatment, in the absence of the *P. versicolor* colonies, was statistically higher (p = 0.001), showing a mean value of 39.46% (Figure 2).

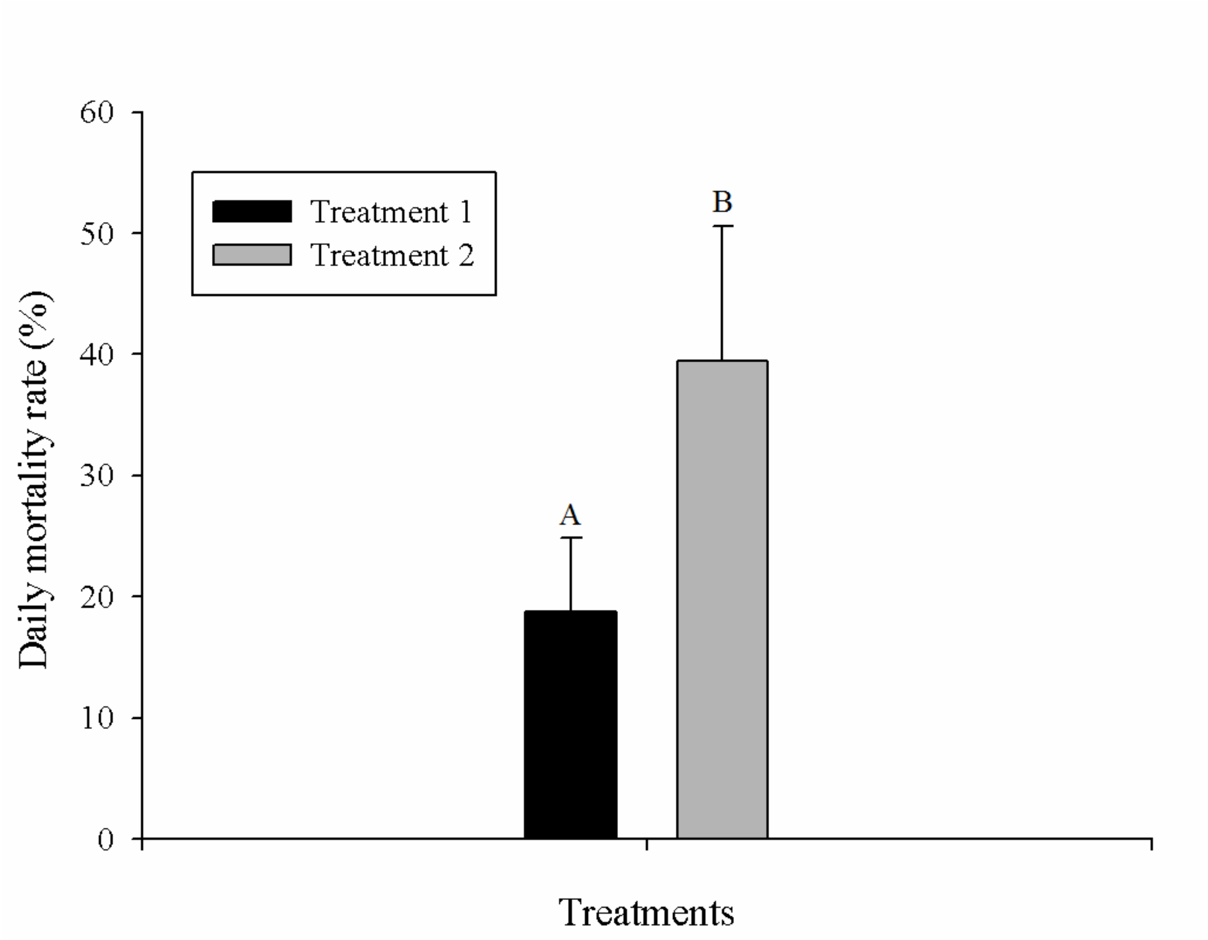

Figure 2: Daily mortality rate (%) for treatments T1, with the *P. versicolor* colonies, and T2, without the *P. versicolor* colonies.

At the time of the field observation, 90 to 100% of the *A. monuste orseis* mortality was found to be a result of predation by the social wasp *P. ignobilis* (Figure 3), for both treatments.

Figure 3: *Polybia ignobilis* predating *Ascia monuste orseis* on a kale leaf in treatment T2.

This wasp, found in great numbers, mostly during the initial stages of the experiment, was evident in the T2 treatment, which lacked the *P. versicolor* colonies. Recognized as the principal predator of *A. monuste orseis,* the *P. ignobilis* demonstrated mortality rates of 50, 17.5, 65.5 and 65.5% for the 2nd, 3rd, 4th and 5th instars, respectively (Picanço et al., 2010). The third and fourth instars revealed mean values similar to those identified in T2.

For the T1 treatment, the findings revealed a very low predation rate, particularly in the first five days (10.4%), which were statistically below (p = 0.031) the average recorded in the other ten days (25%). This was probably because of the necessity to separate the two areas (900 meters) in order to minimize the likelihood of the *P. versicolor* foraging in the T2 treatment. The sample area T2 was thus nearer to the horticulture section of the Campus, which supported a variety of cultures like cucurbitaceae, lettuce, tomato, sunflower and other brassicaceae, providing a more heterogeneous ecosystem, which positively affected the prey availability for *P. ignobilis*, with respect to the T1 sample area.

This vespid preys on a variety of insects including *Edessaru fomarginata* (De Geer), *Chlosynela cinfasaunderssi* Doubleday, *Diaphania hyalinata* (L.), *Diaphania nitidalis* Cramer, *Diabrotica speciosa* (Germar), *Diatraea* sp., *Elasmopalpus lignosellus* (Zeller), *Heliothis zea* (Boddie), *Mimosi ceryahempeli* (Cockerell), *Mocis latipes* (Guenée), *Pectinophora gossypiella* (Saunders), *Spodoptera frugiperda* (Smith) and *Utetheisa ornatrix* (L.) (Souza & Zanuncio, 2012), which might have induced it to migrate more quickly to the T2 treatment.

On comparing the two treatments in terms of the mortality rate, a similarity ($p = 0.662$) was noted between days 6 and 15 (Figure 4); this occurred because of the rise in the foraging activity of *P. ignobilis* evident from Treatment T1. Such an escalation in the *P. ignobilis* foraging activity might be linked to the more intense defoliation in the kale precipitated by *A. monuste orseis*, which most likely stimulated a higher degree of sinomonium secretion, which in turn attracted more numbers of these predatory wasps. When plants experience a herbivorous attack, they emit a wide variety of volatile substances in large quantities, induced by these herbivores (HIPVs). Their natural enemies use these secretions to find their hosts / prey. Such behavior has been recorded earlier for *P. ignobilis* which forages on *Passiflora edulis* Sims (Raw, 1998). Other species belonging to genus *Polybia* are also drawn to plants that have experienced herbivore attacks (Saraiva et al., 2017).

After being attracted to the T1 treatment area, characterized by abundant food supply, the *P. ignobilis* began to forage frequently here, exhibiting a behavior pattern reported earlier for this species (Raw, 1998). The social wasp workers seek only food. They are opportunistic (Michelutti et al., 2017), and return to hunting in the regions where they had met with success during prior trips. Many times, they hunt and feed on the same prey species (Bichara-Filho et al., 2009). To optimize such foraging behaviors, signals are exchanged among the workers to enable the resources to be gathered in for the colony (Taylor et al., 2011). This behavior was observed in the *Polybia occidentalis* (Olivier) colonies (Schueller et al., 2010).

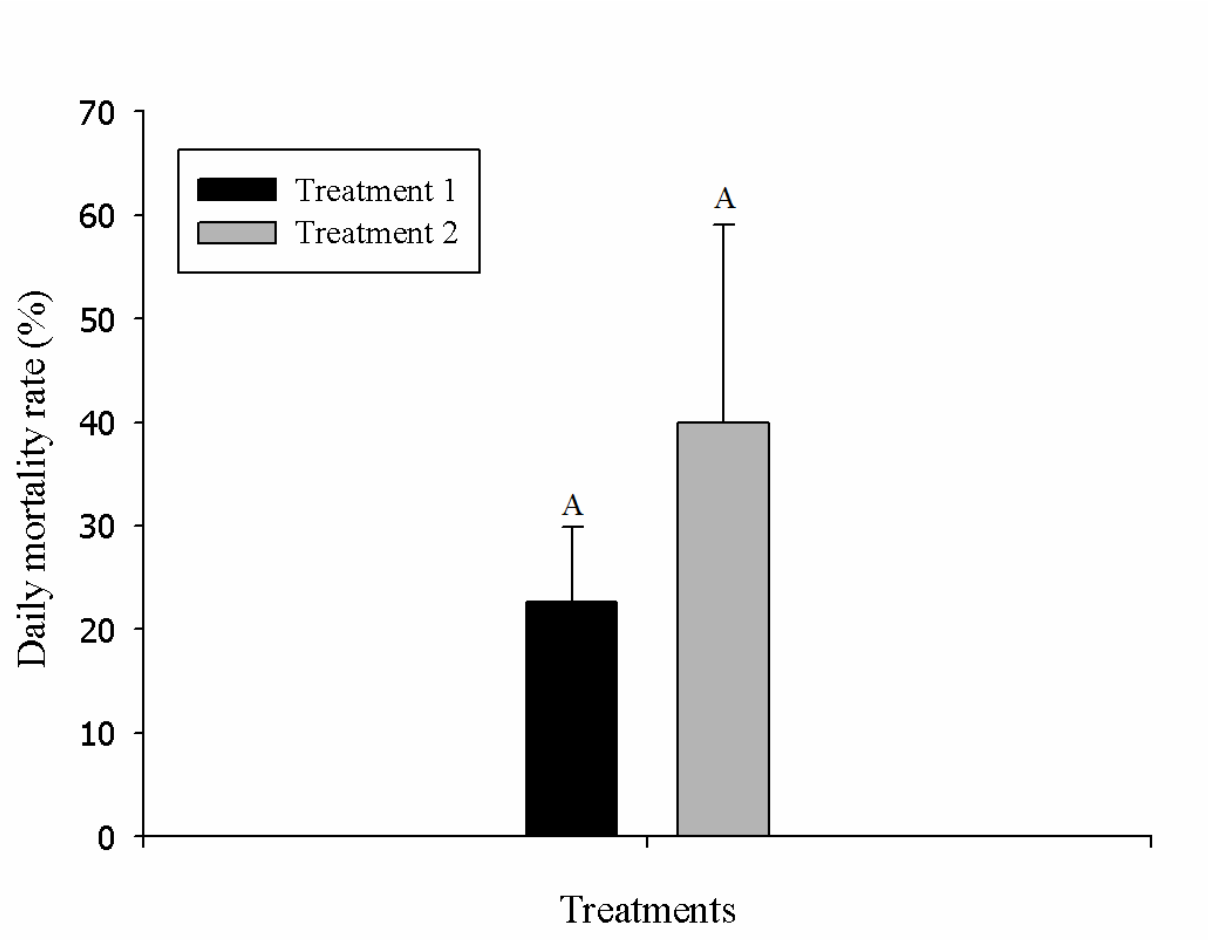

Figure 4: Daily mortality rate (%) from day 6 to 15 of the experiment for treatments (1), with the *P. versicolor* colonies, and (2), without the *P. versicolor* colonies.

For both treatments no regression analysis model was fitted to the daily data on the predation rate, taking into consideration the variables "daily temperature" and "relative humidity". This was most likely because of the low variations in the temperature and humidity during the 15 experimental days.

The translocations of the *P. versicolor* colonies were completely successful, and all four colonies remained unchanged throughout the experiment, with means of 32, 34, 21 and 14 wasps being recorded, respectively, per nest. However, during the observation period, these colonies were only slightly active, with merely three predatory attacks by these wasps on *A. monuste orseis* being recorded. During the experiment, the mean temperature was 22°C and the mean relative humidity 62.2%. These values may have caused the decline in the foraging activity of *P. versicolor*, which is much greater under conditions of high light intensity and humidity and, particularly so at high air temperatures (Elisei et al., 2010), decreasing thus between the months May and September (Elisei et al., 2013). The return of the *P. versicolor* workers to prey on the eucalyptus plantation during the cold and dry seasons is very minimal (Elisei et al., 2010). Normally, the higher levels of temperatures, light intensity, humidity and air velocity favor the well being of the foraging of social wasps (De Castro et al., 2011).

The foraging demand is likely stimulated by the climatic variables, as well as the biological needs of the colony (Detoni et al., 2015). When the experiment was concluded, only larvae were found present in a nest and with several generalized cells, implying a colony declining phase. Nests which support a decreasing number of immature ones, also experience a drop in the food collection. The prey supplies protein essential for offspring growth and development; therefore, the quantity of prey captured using fodder is an indirect estimation of the number of immature wasps and thus, the protein demand of the colony (Canevazzi & Noll, 2011).

The foraging behavior pattern evident in *P. versicolor* is not directed by a queen or any other individual exerting control, but arises only based on the colony requirements (De Souza & Prezoto, 2012a). Although they lack a queen, the workers carry on the foraging activity (De Souza & Prezoto, 2012a). Aggressive behavior among the individuals induces exit foraging, reducing the number of workers as the needs of the colony decline (De Souza & Prezoto, 2012b). Besides, the return of workers which exhibit foraging is the main stimulus which initiates the activities within the colony (De Souza & Prezoto, 2012a).

Carbohydrates and proteins are amenable to storage within the cells for consumption at a later date, and form a good store of reserve for the unfavorable seasons (Michelutti et al., 2017); this results in a reduction in the foraging activities. Such storage abilities have been recorded earlier for the colonies of *Polistes simillimus* Zikán, *Polybia paulista* (Von Lhering), *P. occidentalis*, *Mischocyttarus drewseni* (Saussure) and *Mischocyttarus cassununga* (Von Ihering) (Michelutti et al., 2017). However, foraging activities for water are also observed to decline during the cold and dry seasons, as water is principally utilized in the colony for keeping it cool, a finding earlier reported for *P. versicolor* (Elisei et al., 2013).

The foraging behavior of *P. versicolor* for plant fiber is also at a minimum during the cold and dry seasons, as this resource is mainly required during the demographic explosion phase within the colony, to building and expand the nest cells (Elisei et al., 2010), although such activities are not noticeable in the translocated nests. Foraging for vegetable fibers occurs when the worker uses the jaw to shave the vegetal substrate, including stems, trunks or other such materials. This process takes place more easily when the substrate is moist, and the plant fibers are soft (Elisei et al., 2010).

The two locations without the presence of the wasp colonies registered a similar daily predation rate (Figure 5), indicating that once the first few days of the experiment were over, the location of the treatment did not influence the results.

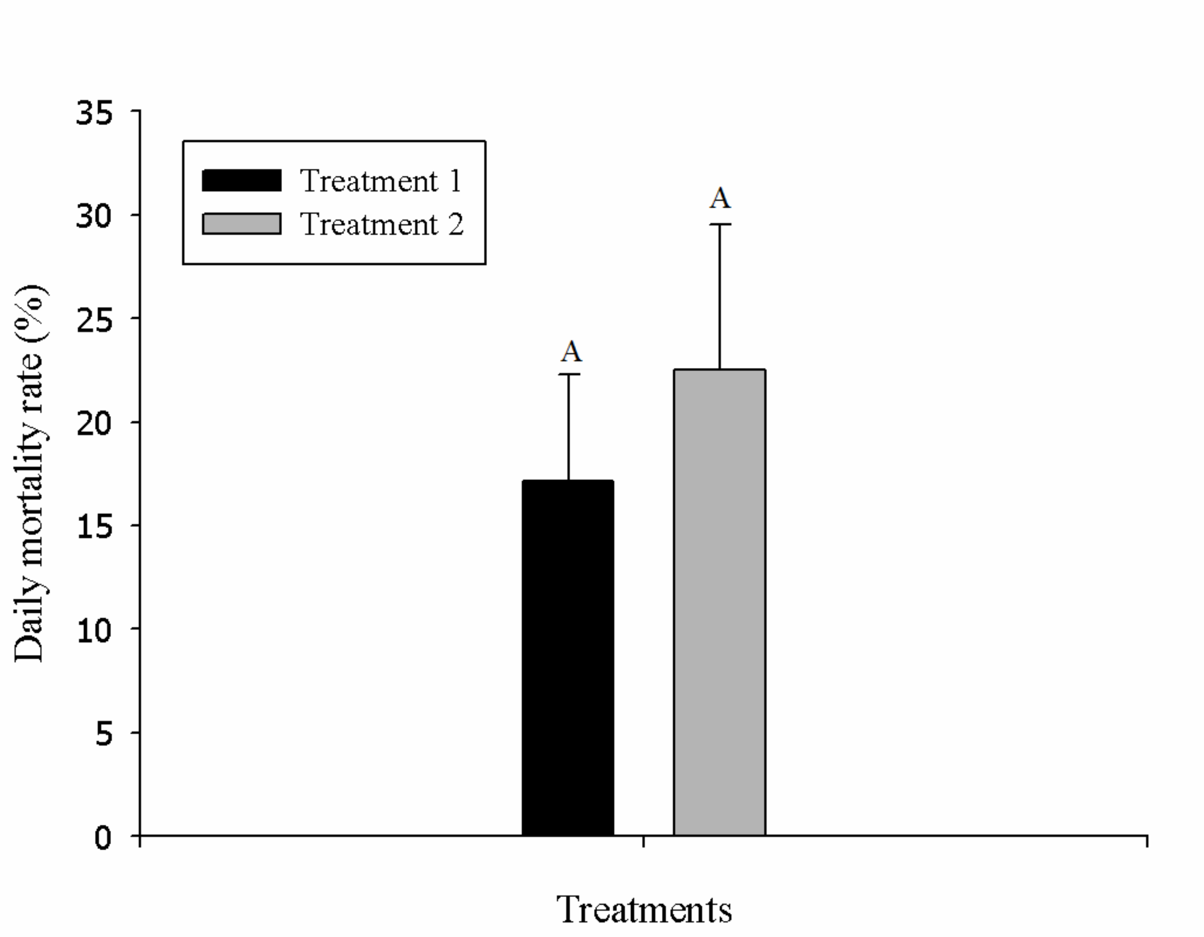

Figure 5: Daily mortality rate (%) for Treatments (1), without the *P. versicolor* colonies, and (2), without the *P. versicolor* colonies.

Conclusions

1 - The translocation of the *Polistes versicolor* colonies onto the kale leaves during the cold and drought periods was ineffective in controlling the *Ascia monuste orseis* population.
2 - *Polistes versicolor* obtained low foraging activity during the experiment period, and consequently, low predation on *Ascia monuste orseis*.

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