Ecology of Vespidae (Hymenoptera)Predators in *Coffea arabica* Plantations

by

Marcelo Coutinho Picanço[1], Ivênio Rubens de Oliveira[2], Flávio Lemes Fernandes[3*], Hermínia Emília Prieto Martinez[4], Leandro Bacci[5] & Ézio Marquez da Silva[3]

ABSTRACT

Social Vespidae exhibit control of *Leucoptera coffeella* (Lepidoptera: Lyonetiidae) in Brazil. The objective was to determine the ideal unit for sampling of predaceous Vespidae in coffee crops in the vegetative and reproductive phases. This research was conducted in two coffee plantations in Viçosa, MG. The factors being studied were: crop phase, canopy thirds, branch type, exhibition side of the plant to solar light and the position of the leaf on the branch. The number of predation mines by Vespidae on all the leaves of each evaluated plant was recorded. In coffee plants in the vegetative phase the best sampling unit of the Vespidae was the 5th or 6th pair of leaves on the primary plagiotropic branches of the median third of the canopy. In coffee plants already in the reproductive phase the best unit for sampling Vespidae were leaves on the third apical of the 4th or 6th pair of leaves on primary plagiotropic branches on the plant face exposed to the sun in the afternoon period or on the median third on the 5th pair of leaves of the plant face exposed to the sun in the afternoon period.

Key words: social insects, *Coffea arabica*, predator, sampling, coffee leaf ~~miner, *Leucop*~~*tera coffeella*.

[1]Departamento de Entomologia, Universidade Federal de Viçosa, Campus de Viçosa, s/n, 36570-000 Viçosa, MG, Brasil

[2]Empresa Brasileira de Pesquisa Agropecuária, Embrapa Tabuleiros Costeiros, Av. Beira Mar, 3250 Sementeira49025-040 Aracaju, SE, Brasil

[3]Instituto de Ciências Agrárias, Programa de Pós-Graduação em Produção Vegetal, Universidade Federal de Viçosa, Campus de Rio Paranaíba, 38810-000 Rio Paranaíba, MG, Brasil

[4]Departamento de Fitotecnia, Universidade Federal de Viçosa, Campus de Viçosa, s/n, 36570-000 Viçosa, MG, Brasil

[5]Universidade Federal de Sergipe, Centro de Ciências Biológicas e da Saúde, Departamento de Engenharia Agronômica, Av. Marechal Rondon, s/n, Cidade Universitária Prof. "José Aloísio de Campos" Jardim Rosa Elze, 49100-000 Aracaju, SE, Brasil

Author for correspondence: flaviofernandes@ufv.br

INTRODUCTION

Social Vespidae have nests built in trees or in the ground. Egg-laying is executed by the founding queen of the nest which due to its dominant activity obstructs the egg-laying or even destroys the eggs produced by other queens. The workers have protective, nest expansion, raising newborn (eggs, larvae and pupas) and foraging roles.Foraging is carried out during the day to collect nectar and other insects. These sources will be used as food for larvae and adults (Giannotti *et al.* 1995; Raveret Richter 2000). Social Vespidae capture insects of several orders, mainly Lepidoptera larvae (Matsuura 1968; Akre 1982; Caron & Schaefer 1986; Raveret Richter 1990).

Vespidae predators have an important role in the natural control of populations of pest-insects in forest and crops like coffee. Coffee crops shelter a great diversity of Vespidae predators like: *Brachygastra lecheguana* Latr., *Eumenes* sp., *Polistes versicolor* (Oliv.), *Polybia occidentalis* Oliv., *Polybia paulista* Ihering, *Polybia scutellaris* White, *Protonectarina sylverae* Saussure, *Protopolybia* spp. and *Synoeca cyanea* L. These social wasps exercise great control on one of the main pests of this crop, the coffee leaf miner *Leucoptera coffeella (*Guer.-Mènev.) (Lepidoptera: Lyonetiidae) (Nogueira Neto 1940; Fernandes *et al.* 2008; Fernandes *et al.* 2009). During the day the adults of these wasps fly over the coffee plants searching for leaves that have mines made by *L. coffeella* caterpillars. When the wasps locate a mine they check if it has caterpillars inside. If it does, they tear the mine open with their oral appliance, capture the caterpillars, grind them and transport them to their nests. So, mines that suffer predation show tears which makes the evaluation of the populations of these predator insects possible (Pereira *et al.* 2007a,b).

One of the relevant aspects in field studies of social Vespidae is determining appropriate place of occurrence to evaluate their populations. These studies are of great importance in basic ecology works as well as in applied ecology (Tibbetts 2007; Fernandes *et al.* 2008).

In selecting the place of occurrence to be used in the evaluation of natural populations it is necessary that it be representative and makes fast sampling possible. According to the criterion for representativeness the best place of occurrence is that which correlates more with absolute density. However, this criterion is often not used in determining the sampling unit to create

sampling plans for social Vespidae. This is due to the difficulty in determining the absolute density of these insects, especially in large plants like the coffee plant that, due to its many leaves, makes determining their absolute densities difficult (Gusmão *et al.* 2004; Bacci *et al.* 2006; Moura *et al.* 2007).

In evaluations of social Vespidae populations it is possible to evaluate the number of nests or the adult population. In the evaluation of the adult population the applicable variables are density (obtained by direct counting or traps) or predation rate. In the evaluation of these insects as predators, the use of predation rate is the most appropriate form of monitoring these populations in natural environments (Fernandes *et al.* 2008).

As such, this work had as its aim the determining of the place of occurrence to assist in studies of social Vespidae predators in coffee crops in the vegetative and reproductive phases.

MATERIALS AND METHODS

This inquiry was carried out in two *C. arabica* fields on the Universidade Federal de Viçosa, Viçosa, Minas Gerais State, Brazil. This period was used because of the greater attack frequency of *L. coffeella* on coffee plants and also because the predation rate of this insect by social Vespidae is greater (Pereira *et al.* 2007a,b). The crops were not irrigated and the cultural treatments were carried out as described by Zambolim (2001). The plants were of the "Catuaí" variety and the spacing used was 3 x 1 m. The plants in these crops were in both the vegetative phase and the reproductive phase. In the crop in the vegetative phase the plants were nearly 19 months old at the beginning of the evaluations and occupied about 30 ha. The crop in the reproductive phase of the was nearly seven years old and occupied around 70 ha. The vegetative phase of the coffee plant does not produce fruit, but at about 30 months old it produces its first harvest (plant in reproductive phase).

The factors being studied were the phases of crop (vegetative or reproductive), thirds of the canopy (apical, median or basal), type of branch (primary or secondary plagiotropic), exposure of the plant to solar light (exposure of the face of the plant to the sun during the morning or afternoon periods) and the positions of the leaf on the branch (1st to the 8th pair of leaves totally expanded from the apex of the branch). In each crop the number of mines that received predation by adult social Vespidae on all the leaves of each evaluated

plant were recorded. For each one of these leaves the canopy thirds, the type of branch, the exposure of the plant to solar light and the position of the leaf on the branch were recorded.

Thirty four plants were evaluated in the crop in the vegetative phase and 43 plants in the crop in the reproductive phase. This was the maximum number possible to evaluate using 10 people, since the plants had up to 5,000 leaves and each person was able to evaluate one plant per day. The evaluated plants were apced equally in the crop in order to obtain systematized sampling points (Bacca *et al.* 2006; Moura *et al.* 2007).

Absolute densities were calculated (number of mines that received predation by plant) and the relative densities in each sampling unit (number of mines that received predation/sampling unit). In order to select the ideal unit for sampling of the social Vespidae the criteria of representativeness and sampling speed were used. Based on the criterion of speed, samples that presented at least a 20% frequency so that localization was fast were selected.

By the criterion of representativeness samples whose relative densities correlated with absolute density were selected. For all of these, Pearson correlations were calculated between absolute and relative densities in each sampling unit. Ideal samples were considered those that presented a significant correlation in the t test ($p<0.05$). When more than one sampling unit presented significant correlation, the relative densities were subjected to the simple linear regression analysis of $p<0.05$ as a function of absolute densities. An ideal sample was considered as one whose curve presented a greater inclination. These proceedings were proposed by Podoler & Rogers (1975) to select the phase or factor of mortality better represented by the variation of total mortality in the studies of ecological life charts. As such, in the present work the use of these statistical methods in selecting a unit to create a sampling plan based on the criterion of representativeness is proposed, since it is intended to select which sampling unit better represents the variation in absolute density.

RESULTS

Plants in vegetative phase

Positive and significant correlations were verified ($p<0.05$) between absolute densities with relative densities of Vespidae predators in the three thirds of the canopy. The regression curve for predation on leaves in the median

Table 1. Pearson's correlation between the absolute density of Vespidae predators (mines predates/leaf) with the relative densities in the sampling units and regression curve of these relative densities as a function of the absolute densities in vegetative phase coffee plants.

Sampling unit	Pearson's correlation			Regression curve				
	r	t	p	Intercept	Inclination	R^2	F	p
Canopy								
Apical	0.6	4.47	<0.0001	0.002	0.91 (0.71-1.11)	0.4	19.95	<0.0001
Median	0.9	9.15	<0.0001	-0.013	1.75 (1.56-1.94)	0.7	83.95	<0.0001
Basal	0.6	4.4	<0.0001	0.003	0.72 (0.56-0.88)	0.4	19.36	0.0001
Plant face exposed to the sun								
Morning period	0.8	7.42	<0.0001	-0.23	0.80 (0.70-0.91)	0.6	55	<0.0001
Afternoon period	0.6	4.22	0.0001	2.08	0.86 (0.66-1.07)	0.4	17.84	0.0002
Type of branch								
Primary plagiotropic	0.9	10.4	<0.0001	0.01	1.23 (1.11-1.35)	0.8	108	<0.0001
Secondary plagiotropic	0.2	1.17	0.1264	0	0.11 (0.01-0.21)	0	1.36	0.2529
Position of the leaf on the branch								
1st	0.1	0.57	0.2852	*	*	*	*	*
2nd	0	0.24	0.4062	*	*	*	*	*
3rd	0.5	3.54	0.0006	-1.75	0.72 (0.52-0.92)	0.3	12.52	0.0013
4th	0.5	2.93	0.0031	-0.17	0.93 (0.61-1.25)	0.2	8.61	0.0061
5th	0.6	3.76	0.0003	0.09	2.06 (1.51-2.61)	0.3	14.12	0.0007
6th	0.4	2.11	0.0215	2.98	1.46 (0.76-2.16)	0.1	4.44	0.043
7th	0.6	3.97	0.0002	-1.03	4.12 (3.08-5.16)	0.3	15.77	0.0004
8th	0.2	1.11	0.1372	*	*	*	*	*

* Regression analysis was not carried out since the sampling unit had already been selected by the correlation analysis.

third presented a greater inclination than the curves of the apical and basal thirds (Table 1). Therefore, in the vegetative phase coffee crops the sampling of social Vespidae predators should be carried out on leaves from the median third of the canopy.

Table 2. Pearson's correlations between the absolute density of predaceous Vespidae (mines/leaf) on the plant with the relative densities in the canopy thirds and regression curves of these relative densities as a function of the absolute density in reproductive phase coffee plants.

Sampling unit	Pearson's correlation			Regression curve				
	r	t	p	Intercept	Inclination	R^2	F	p
Thirds of the canopy								
Apical	0.86	10.79	<0.0001	0.0078	0.93 (0.81-1.05)	0.6	61.94	<0.0001
Median	0.89	12.76	<0.0001	-0.0039	1.05 (0.96-1.14)	0.8	127.3	<0.0001
Basal	0.9	12.86	<0.0001	-0.001	0.88 (0.80-0.97)	0.8	115.9	<0.0001

Regarding the sun exposure of the plant, verification of the two surfaces of the plant presented a positive and significant correlation ($p<0.05$) to total predation, and its regression curves presented similar inclinations (Table 1). So, in vegetative phase coffee crops the sampling of the social Vespidae predators can be done on either surface of the plant.

Among the types of branches of the plant, it was determined that only the predation that occurred on the primary plagiotropic branches presented positive and significant correlation ($p<0.05$) with the total predation (Table 1). So, in vegetative phase coffee crops the sampling of the social Vespidae predators must be carried out on leaves of the primary plagiotropic branches.

Among the pairs of leaves of the branch, positive and significant correlations were verified ($p<0.05$) among predation that took place in the 3rd, 4th, 5th, 6th and 7th pairs of insertion of the leaves in the branches with total predation in the median third of the canopy. However, leaves from the 7th pair were not selected because fast sampling was not possible to present less than a 20% frequency. The predation regression curves in the 5th and 6th pairs as a function of total predation presented greater inclinations than the curves of the 3rd and 4th pairs (Table 1). Therefore, in vegetative phase coffee crops the sampling of social Vespidae predators must be carried out on leaves of the 5th or 6th pair.

Plants in reproductive phase

Positive and significant correlations were observed ($p<0.05$) between absolute density to the total *L. coffeella* predation by Vespidae with predation

Table 3. Pearson's correlations between the absolute density of Predaceous Vespidae (mines/leaf) on the apical third of the canopy with the relative densities in the sampling units and regression curve of these densities relative to the function of absolute densities in reproductive phase coffee plants.

Sampling unit	Pearson's correlation			Regression curve				
	r	t	p	Intercept	Inclination	R^2	F	p
Plant face exposed to the sun								
Morning period	0.8	7.36	<0.0001	-0.07	0.82 (0.71-0.93)	0.6	54.15	<0.0001
Afternoon period	0.9	10.9	<0.0001	-0.46	1.23 (1.12-1.35)	0.8	118.9	<0.0001
Type of branch								
Primary plagiotropic	1	23.5	<0.0001	-0.23	1.27 (1.21-1.32)	0.9	552.9	<0.0001
Secondary plagiotropic	0.6	4.53	<0.0001	0.48	0.78 (0.61-0.95)	0.4	20.51	<0.0001
Position of the leaf on the branch								
1st	0.4	2.45	0.0092	0.51	0.21 (0.13-0.30)	0.1	6.04	0.0183
2nd	0.8	7.44	<0.0001	-0.35	0.66 (0.57-0.75)	0.6	55.33	<0.0001
3rd	0.8	9.39	<0.0001	-1.92	1.57(1.40-1.74)	0.7	55.33	<0.0001
4th	0.9	10.7	<0.0001	-1.68	2.11 (1.92-2.31)	0.7	114.7	<0.0001
5th	0.8	8.18	<0.0001	-0.54	1.24 (1.09-1.40)	0.6	66.92	<0.0001
6th	0.5	3.78	0.0003	2.09	1.85 (1.46-2.24)	0.4	22.23	<0.0001
7th	0.6	4.71	<0.0001	2.43	1.18 (0.87-1.49)	0.3	14.3	0.0005
8th	0.6	2.5	0.0592	*	*	*	*	*

* Regression analysis was not carried out since the sampling unit had already been selected by the correlation analysis.

intensities in the three thirds of the canopy. The regression curves of the relative densities of the apical and median thirds presented the greatest inclinations (Table 2). Therefore in reproductive phase coffee crops the sampling of social Vespidae predators must be carried out on apical or medium third leaves.

On the apical third of the canopy, the leaves exposed to the sun in the afternoon period better represented *L. coffeella* predation by social Vespidae. In this canopy third the primary plagiotropic branches better represented *L. coffeella* predation by Vespidae. The 4th and 6th leaf pairs also better represented

Table 4. Pearson's correlations between the absolute density of predaceous Vespidae (mines/leaf) on the median third of the canopy with the relative densities in the sampling units and regression curve of these densities relative to the function of absolute densities in reproductive phase coffee plants.

Sampling unit	Pearson's correlation			Regression curve				
	r	t	p	Intercept	Inclination	R^2	F	p
Plant face exposed to the sun								
Morning period	0.71	6.38	<0.0001	0.10	0.75 (0.63-0.87)	0.50	40.63	<0.0001
Afternoon period	0.75	7.17	<0.0001	0.11	1.14 (0.98-1.29)	0.49	37.18	<0.0001
Type of branch								
Primary plagiotropic	0.45	2.73	0.0053	1.86	0.72 (0.46-0.98)	0.20	7.45	0.0105
Secondary plagiotropic	0.72	5.95	<0.0001	0.52	0.77 (0.64-0.90)	0.53	35.41	<0.0001
Position of the leaf on the branch								
1st	0.52	3.86	0.0002	0.03	0.15 (0.12-0.20)	0.27	14.91	0.0004
2nd	0.58	4.61	<0.0001	0.21	0.28 (0.22-0.34)	0.34	21.29	<0.0001
3rd	0.78	7.94	<0.0001	0.48	0.73 (0.63-0.82)	0.61	63.04	<0.0001
4th	0.85	10.46	<0.0001	0.82	1.47 (1.17-1.77)	0.37	24.18	<0.0001
5th	0.61	4.92	<0.0001	-0.29	2.02 (1.79-2.24)	0.66	78.78	<0.0001
6th	0.81	8.88	<0.0001	0.44	1.22 (0.96-1.48)	0.35	22.20	<0.0001
7th	0.59	4.71	<0.0001	-2.14	0.90 (4.36-5.44)	0.68	81.62	<0.0001
8th	0.82	3.03	0.0601	*	*	*	*	*

*Regression analysis was not carried out since the sampling unit had already been selected by the correlation analysis.

L. coffeella predation by Vespidae (Table 3). Therefore, in leaves from the apical third of reproductive phase coffee plants the sampling of social Vespidae must be carried out in the 4th or 6th leaf pairs of primary plagiotropic branches plant surfaces exposed to the sun in the afternoon period.

In the medium third of the canopy the leaves exposed in the sun in the afternoon period better represented *L. coffeella* predation by Vespidae. In this canopy third, leaves of the primary plagiotropic branches as well as the secondary plagiotropic branches represented similar *L. coffeella* predation by Vespidae. The leaves of the 5th pair better represented *L. coffeella* predation by Vespidae (Table 4). Therefore, in leaves from the median third of reproductive phase coffee plants the sampling of social Vespidae must be carried out in the 5th pair of leaves in plants exposed to the sun in the afternoon period.

Therefore, in coffee plants in the vegetative phase the best units for sampling social Vespidae were the 5th or 6th pair of leaves of primary plagiotropic branches of the median third of the canopy. In reproductive phase coffee plants the best unit for sampling social Vespidae was in leaves of the apical

third in the 4th or 6th pair of leaves of primary plagiotropic branches in plants exposed to the sun in the afternoon period or in the median third in the 5th pair of leaves of the plant exposed to the sun in the afternoon period.

DISCUSSION

The preference for monitoring specific places of occurrence of social Vespidae predation is due to the fact that these better represent the absolute density fluctuations of these insects on the plant. Therefore, in plants with greater predation by Vespidae greater densities of this insect will occur in these sampling units or vice-versa. As such, it is possible to infer that the factors that affect the absolute densities of these insects in the plants will also affect its relative densities in the sampling units selected. This fact does not take place with equal intensity in other parts of the plant. Therefore, factors like climatic elements, prey density, toxins, nutrients and allelochemicals present in the leaves in the ideal Vespidae sampling units must have similar influence to what occurred in the plant as a whole (Bechinski & Pedigo 1982; Schuster 1998; Pedigo & Rice 2006).

Therefore, factors like weather or climate should have different impacts on Vespidae in the different canopy thirds. These impacts should be more intense in the apex of the plants due to the leaves being more exposed to rain and extreme temperatures. Inversely, the basal third where the leaves are less exposed to weather climates should be the opposite. Therefore the fact of the canopy median third being the ideal place for Vespidae sampling in vegetative phase as well as in reproductive phase plants should be related to the greatest density of *L. coffeella* caterpillars or intermediate exposure of Vespidae to weather climate conditions in this part of the plant (Villacorta 1980; Carracedo *et al.* 1991; Nestel *et al.* 1994).

In general the leaves exposed to the sun in the afternoon period were better for sampling Vespidae than those exposed to the sun in the morning. Therefore, in leaves exposed to the sun in the morning, the variation of relative predator wasp densities differs from the rest of the plant. Among the factors that can influence this response are the effects of air temperature and luminosity on the flight activity of Vespidae. Verification of greater flight activity of these insects in periods of higher temperature and luminosity was carried out and

it is a fact that this takes place in the afternoon period (Ghule *et al.* 1989; Leite *et al.* 2001).

In general, the leaves of the primary plagiotropic branches were better for sampling Vespidae than the secondary plagiotropic branches. Such results could be associated with the fact that secondary plagiotropic branches are more exposed to the weather because of being located in the most external part of the plant, which has a negative influence both on Vespidae and on its prey (Pereira *et al.* 2007a,b).

On the whole, the ideal unit for sampling Vespidae was located on leaves from the 4th to 6th pair. This unit, which is different from those recommended in the works of Villacorta & Tornero (1982); Villacorta & Gutierrez (1989); Bearzoti & Aquino (1994); Villacorta & Wilson (1994) based on studies about the evaluation of samples adequate for the evaluation of the nutrient content on the leaves. Therefore the factors that influence Vespidae density should be different from what affects the nutrient contents in the leaves. A possible mechanism for this phenomenon could be the previously mentioned higher incidence of toxins on older leaves like those present at the end of the branch or even the greater exposure of the leaves of the initial portion of the branches to weather (Caixeta *et al.* 2004).

In summary, our study provides important information for understanding the ecology of predation by wasps in coffee crops, in addition to proposing methodology for evaluation of Vespidae predator populations in these agroecosystems.

ACKNOWLEDGMENTS

This research received financial support from CAPES, CNPq, FAPEMIG, PNPD/Café. We thank Dra. Enedina Sacramento and Dr. Jeff Oar for critically reading a draft of the manuscript and the manuscript referees were greatly appreciated.

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