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ARTICLE

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Long-term study in *Leucoptera coffeella* population from southern Minas Gerais, Brazil

Rogério A. Silva[1], Leopoldo F. O. Bernardi[2], Christiano S. M. Mato[1], Alessandro B. Pereira[1], Elifas N. Alcântara[1]

1- Empresa de Pesquisa Agropecuária de Minas Gerais – EPAMIG Sul/ URESM, CEP 37200–900, Lavras, MG, Brazil.; 2-Departamento de Entomologia, Universidade Federal de Lavras – UFLA, Campus Universitário, CP 3037, CEP 37200–900, Lavras, MG, Brasil..
*Corresponding author: leopoldobernardi@gmail.com
Short title: Long–term study in coffee leaf miner population

Abstract

The mine bug, *Leucoptera coffeella* (Guérin-Mèneville, 1842) (Lepidoptera: Lyonatiidae), is considered an important coffee pest as it causes losses to productivity and reduced harvests. The species is mainly controlled through chemical inputs, which can lead to the emergence of resistant populations. Understanding the population dynamics of this species is vital to the search for more adequate and efficient management programs. In this work, we sought to understand how environmental factors (temperature and precipitation) affect the occurrence of attacks by *L. coffeella* on coffee leaves and determine if these same factors influence wasp predation rates on the caterpillars of this lepidopteran. The results showed that the occurrence of *L. coffeella* larvae is correlated with environmental temperature, with greater abundance during the hot months of the year. There was also greater predation of *L. coffeella* by wasps during this period, which are attracted to coffee plantations by the abundance of larvae that they use as a food resource and, thus, act as biological controllers. Precipitation is also an important control factor for *L. coffeella* because it reduces the abundance of this pest and helps control the species even during months of greater lepidopteran abundance.

Keywords: Leaf miner, Coffee, Biology, Control, Lepidoptera, Climate variability, Predation.

Introduction

Coffee (*Coffea arabica* Lineu) is an important commodity that is produced in several countries in Asia (e.g., Vietnam, Indonesia, India and Colombia), Africa (e.g., Uganda and Ethiopia) and the Americas (e.g., Guatemala, Mexico, Honduras, Colombia and Brazil). From production to commercialization and consumption, the products originating from this cultivar drive sectors of the economy that involve more than 120 million people. However, there are many challenges prior to coffee consumption (Krishnan 2017; Osorio 2002), and it is during cultivation and harvest that problems occur that can determine whether a harvest will produce a satisfactory quantity of healthy and quality coffee beans (Reis 2011).

One of the main problems faced by coffee production, especially during the initial stage involving cultivation and pre–harvest, is arthropod pests. These pests can cause early senescence of leaves, fruits, and reduce plant longevity, harvest, fruit quality and, consequently, the quality of the final product (Barrera 2008).

Among the different arthropods that cause damage to coffee production, such as the coffee borer, *Hypothenemus hampei* (Ferrari 1867); red mite, *Oligonychus ilicis* (McGregor 1917); red spot, *Brevipalpus phoenices*; cicada, *Quesada gigas* (Olivier, 1790); and caterpillars of the microlepidopteran mine bug, *Leucoptera coffeella* (Guérin–Méneville), are key pests in Brazil and of great importance in other places such as Colombia, Mexico and Puerto Rico due to the great economic damage that it may cause (Dantas et al. 2020; Vega et al. 2006).

Populations of *L. coffeella*, as well as other coffee pests, have mainly been controlled with agrochemicals. However, the indiscriminate use of insecticides can result in the loss of their efficiency,

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leading to the selection of populations that are resistant to certain chemical compounds (Dantas et al. 2020; Fragoso et al. 2003). In addition, the insecticides used to control *L. coffeella* affects a broad range of species and can cause damage to the environment and the death of non–target insects, such as natural enemies that are capable of controlling pests (Bacci et al. 2006; Fragoso et al. 2002).

Proper management techniques able to prevent pest insect populations from reaching levels that cause damage, as well as their improvement, is a sustainable way to combat species that cause economic losses in agriculture. Furthermore, the implementation of biological control techniques, whether as an alternative or a complementary technique, only becomes an efficient tool after detailed study of the biology of the target pest insect and its natural enemies. Thus, this work aimed at monitoring the long–term (2015–2019) occurrence of *L. coffeella* and the effects of wasp predation on this pest in trees of coffee, in southern Minas Gerais State, Brazil. Coffee is the second most important agricultural exportation product in Brazil, and Minas Gerais state is the main coffee producer, with more than 50% of the country's total production (CONAB 2022), and *L. coffeella* is the most important pest in this crop, causing a great reduction in production. Due this, the present work aimed at a better understanding of how environmental factors (temperature and precipitation) affect the occurrence of attacks by *L. coffeella* on coffee leaves, and whether these environmental factors can also influence wasp predation rates on caterpillars of this lepidopteran.

Materials and Methods

Study area

The study was conducted at the experimental area of EPAMIG (Empresa de Pesquisa Agropecuária de Minas Gerais), in São Sebastião do Paraíso, Minas Gerais state, Brazil (20°54'37.32" 47°06'43.86"W, 837 m). The region has an annual rainfall around 1,400 mm, concentrated from October to April, and an annual average temperature of 20.8ºC. The soil is predominantly composed of Dystroferric Red Latosol (Silva et al. 2018). The experiment was carried out from 2015 to 2019 with *C. arabica* c.v. *Paraíso* (aged six years at the beginning of the experiment), with an open area cultivation mode without the control of environmental variables. Individuals have been sown 0.7 meters apart, in rows spaced by four meters. Coffee cultivation was carried out in accordance with conventional protocols (Alcântara and Cunha 2010), however without chemical control against pest. Weed management was carried out manually or with the aid of a mechanized mower.

Precipitation data were collected throughout the experimental period by the local meteorological station (Vantage Pro2Wireless Weather Station, Davis Instruments, USA), which is permanently installed within the experimental farm where the study was conducted.

Experimental design

Data were collected in 21 plots of four rows of plants (20 plants/row) and evaluated for only the useful area composed of plants located in the two central rows for a total of 80 plants. The densities of *L. coffeella* and predator wasps were evaluated using a total of 525 leaves (25 leaves/plot from the middle third of the plants) collected monthly from January to December of each year. The leaves were subsequently packed in Kraft paper bags, identified and transported to the Laboratório de Entomologia EPAMIG/URESM–EcoCentro Lavras where the following parameterswere evaluated: number of attacked leaves (AL, leaves possessing marks of attack by *L. coffeella* larvae), number of intact larvae (IL, observed presence of live *L. coffeella* larvae), number of predated larvae (PL, observed residual marks corresponding to predation of *L. coffeella* larvae by predatory wasps found in coffee trees in this southern region of Minas Gerais belonging to the genera (*Mischocyttarus*, *Polistes*, *Protopolybia*, *Polybia, Brachygastra*, and *Protonectarina*).

Statistical analysis

The existence, or not, of a relationship among the studied biotic and abiotic variables was evaluated by correlation tests using a generalized linear model (GLM). The tested correlations were as follows: number of attacked leaves x abiotic variables (monthly mean temperature and monthly total precipitation), number of intact larvae present on leaves x abiotic variables, number of predated larvae and abiotic variables, and number of attacked leaves x number of predated larvae. A Poisson error structure, suitable for counting data, was used with correction for under or over dispersion (Quasi–Poisson or Negative Binomial). All models were submitted to residual analysis of the adequacy of the error distribution. Tests with p–values < 0.05 were considered significant.

To facilitate visualization of correlations between variables, collinearity (correlation) between variables was assessed by Pearson correlation analysis, and the results presented as a correlation pyramid.

The generalized linear model analysis were performed using R software (R Development Core Team 2021).

Results

An oscillation with cyclical patterns was observed in the measured biological parameters during the sampling of attacked leaves, with maximum values for each year occurring in warmer months, mainly between September and November (Figure 1, Table 1).

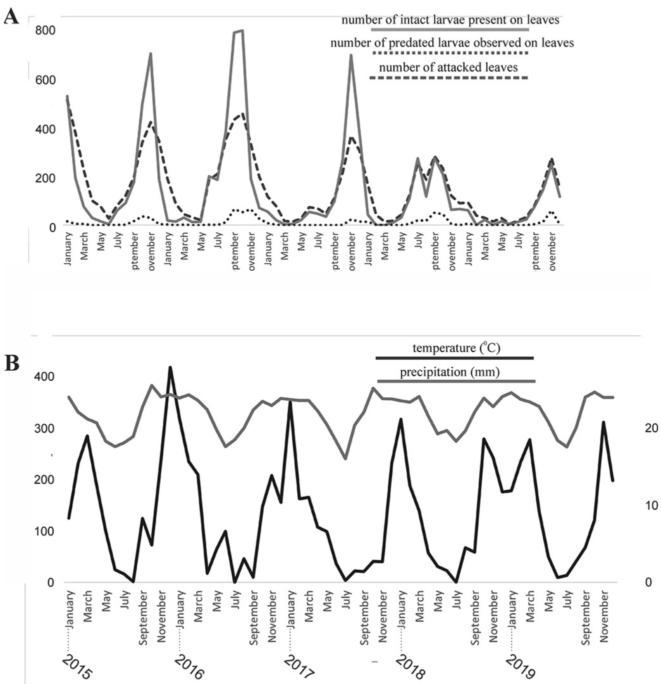

Figure 1: A: Variation in observed values of biological parameters (AL, number of attacked leaves; IL, number of intact larvae present on leaves; PL, number of predated larvae observed on leaves). B: Variation in observed values of abiotic parameters (mean monthly temperature; total monthly precipitation).

Among the tested correlations, temperature was significantly positively correlated with the number of attacked leaves, with the number of intact larvae present on the leaves and with the number of predated larvae on the leaves. Furthermore, the number of predated larvae was significantly positively correlated with the number of attacked leaves, which reinforces the thesis that predator density is dependent on prey

Table 1: Observed values for the studied biotic and abiotic parameters.

Date of collection		AL	IL	PL	Temp	Prec
January	2015	512	528	16	24	125
February	2015	378	193	5	22.1	230.8
March	2015	225	76	5	21.2	285.2
April	2015	100	30	0	20.7	189.8
May	2015	77	16	0	18.3	99
June	2015	27	4	0	17.6	24.9
July	2015	81	61	1	18.1	16.6
August	2015	121	91	2	18.9	1.5
September	2015	197	176	17	22.7	124.4
October	2015	339	496	36	25.5	72.8
November	2015	421	703	30	24	237.4
December	2015	344	188	4	24.3	418.4
January	2016	190	19	3	23.9	318.6
February	2016	87	15	0	24.3	235
March	2016	45	31	2	23.6	209.4
April	2016	32	12	0	22.4	17.8
May	2016	21	13	0	19.8	64.2
June	2016	185	200	2	17.6	99.4
July	2016	209	186	1	18.49	0
August	2016	351	383	11	20	46.4
September	2016	432	788	65	22.34	10
October	2016	458	797	53	23.4	146.8
November	2016	331	189	65	22.9	208
January	2017	117	55	8	23.7	351
February	2017	79	21	2	23.6	162.8
March	2017	17	3	0	23.6	165.6
April	2017	15	5	0	22.2	107.8
May	2017	26	20	0	20.4	98.6
June	2017	73	54	0	18.3	36.6
July	2017	68	47	0	16	3.6
August	2017	47	35	0	20.3	22.6
September	2017	111	97	0	22	21.2
October	2017	216	268	1	25.1	40.8
November	2017	365	696	23	23.8	40.6
December	2017	306	379	15	23.8	230.6
January	2018	166	43	13	23.5	317.4
February	2018	41	0	2	23.3	188.2
March	2018	15	0	0	24.1	139.6
April	2018	18	10	1	21.5	57.4
May	2018	42	31	0	19.2	30.8
June	2018	123	109	5	19.7	23
July	2018	254	273	20	18.3	0.6
August	2018	187	117	18	19.6	67.8
September	2018	283	277	51	22.1	58.8
October	2018	232	208	44	23.9	279.2
November	2018	121	63	5	22.7	242.8
December	2018	89	66	0	24.1	176
January	2019	93	61	6	24.6	178
February	2019	39	1	1	23.7	234.2
March	2019	29	22	0	23.4	277.4
April	2019	15	1	0	22.8	139
May	2019	28	16	0	20.8	50.4
June	2019	5	4	0	18.4	9.4
July	2019	19	13	0	17.5	13.8
August	2019	33	23	0	20	40.8
September	2019	82	77	4	24	68
October	2019	162	145	14	24.6	121.6
November	2019	276	248	60	23.9	311.8
December	2019	152	116	3	23.9	197.8

AL, number of attacked leaves; IL, number of intact larvae present in leaves; PL, number of predated larvae observed in leaves; Temp, mean monthly temperature; Prec, total monthly precipitation.

density (Table 2, Figures 2–5)..

Table 2: Values for correlation tests performed between the studied response and predictor variables, and the error structure used for each model.

Tested correlation	Significance	Model error structure
AL vs Temp	F = 6.71 $p = 0.012$	Quasi–Poisson
AL vs Prec	Not significant	Quasi–Poisson
IL vs Temp	Chi = 73.19 $p = 0.027$	Negative binomial
IL vs Prec	Not significant	Quasi–Poisson
PL vs Temp	Chi = 62.85 $p < 0.01$	Negative binomial
PL vs Prec	Not significant	Quasi–Poisson
PL vs AL	F = 57.68 $p < 0.01$	Quasi–Poisson

(AL, number of attacked leaves; IL, number of intact larvae present on leaves; PL, number of predated larvae observed on leaves; Temp, average monthly temperature; Prec, total monthly precipitation)

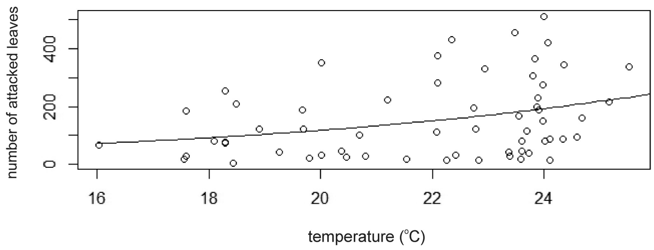

Figure 2: Correlation between the number of attacked leaves and average monthly temperature between January 2015 and December 2019 (F = 6.7135, p = 0.01208) (AL: attacked leaves; temp: average monthly temperature).

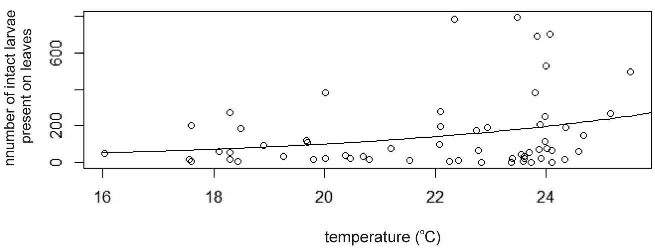

Figure 3: Correlation between the number of intact larvae and average monthly temperature between January 2015 and December 2019 (Chi = 73.19, p = 0.02701) (IL: intact mines; temp: average monthly temperature).

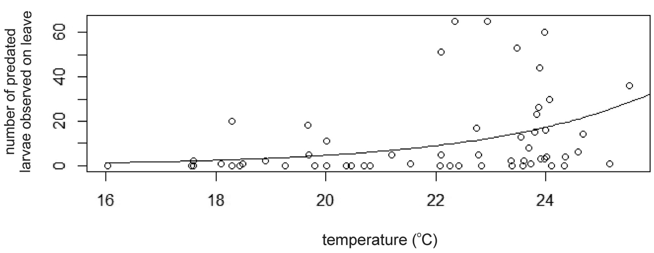

Figure 4: Correlation between the number of predated larvae and the average monthly temperature between January 2015 and December 2019 (Chi = 62,855, p < 0.01) (PL: predated mines; temp: average monthly temperature).

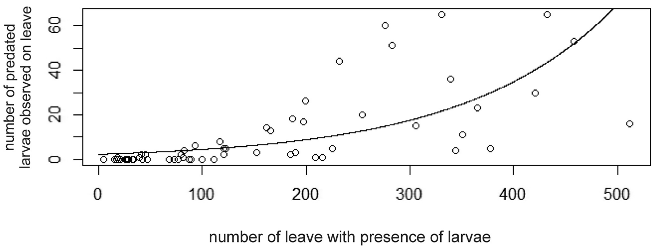

Figure 5: Correlation between the number of predated larvae and the number of atacled leaves between January 2015 and December 2019 (F = 57.68, p < 0.01) (MP: predated mines; FM: mined leaves).

The correlation pyramid shows that the variables with the greatest correspondence are also those with significance in the generalized linear model test, namely attacked leaves and intact larvae (88%), followed by attacked leaves and predated larvae (70%) (Figure 6).

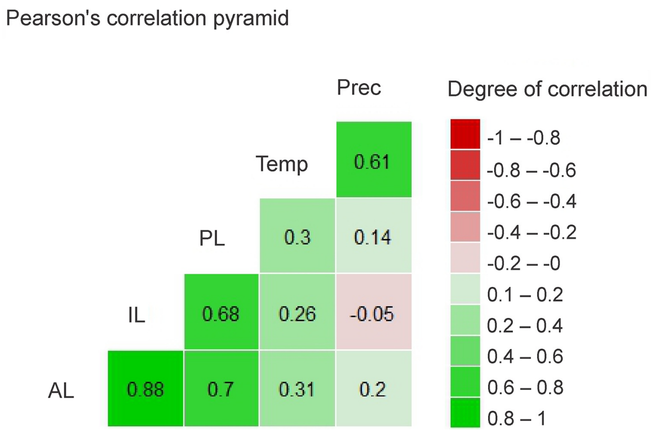

Figure 6: Pearson's correlation pyramid showing the degree and value of the correlations between the studied biological and environmental variables (AL, number of attacked leaves; IL, number of intact larvae present on leaves; PL, number of predated larvae observed on leaves; Temp, average monthly temperature; Prec, total monthly rainfall).

Discussion

The present study demonstrated that the occurrence of *L. coffeella* larvae is positively correlated with environmental temperature, with greater abundance in the hotter months of the year. Furthermore, the increase in *L. coffeella larvae*, which occurs mainly between November and March, attracts predatory wasps to coffee plantations due to the greater abundance of this food resource. As a result, there is an increase in the number of leaves with signs of predation of *L. coffeella* by wasps.

The occurrence of *L. coffeella* is correlated with temperature because changes in this environmental variable can lead to changes in the development time of the egg, larval, pupa and adult (Giraldo–Jaramillo et al. 2019, Notley 1948). Higher temperatures favor development and, thus, reduce the time needed for an insect to complete its life cycle (Giraldo–Jaramillo et al. 2019; Notley 1948), which increases the frequency of reproduction and, consequently, the population size in coffee plantations. However, very high temperatures (i.e., above 30ºC) can damage pupal development (Giraldo–Jaramillo et al. 2019). Studies have found that temperatures of around 25ºC are the most suitable for the development of *L. coffeella* (Giraldo–Jaramillo et al. 2019; Notley 1948), which corresponds to the temperature of the months of when a greater number of larvae was observed.

Even though the greatest number of attacked leaves were observed in the coffee plantation during the warm periods of the evaluated years, it was also the same period with the highest rates of wasp predation. These data corroborate the results of other studies, such as that of Souza et al. (2014) who also observed increased predation accompanying densities of pest infestation. Natural enemies, such as predatory wasps, can accentuate *L. coffeella* mortality in coffee plantations. Thus, the use of attractive plant species that serve as shelter and as alternative food, and which are naturally present in the coffee agroecosystem, is an interesting alternative to maintain and increase the number of agents controlling this pest. Maintaining predators in crop areas using alternative resources has been recommended for other predators such as hemipterans and mesostigmatans (Adar et al. 2014, Silveira et al. 2003). Furthermore, the presence of these natural biological control agents should be considered when making decisions regarding the use of insecticides for the management of *L. coffeella*. The use of selective products is recommended to avoid non–target insects, including natural enemies (Reis and Souza 1996; Gusmão et al. 2000; Fragoso et al. 2001).

There is an abrupt drop in the populations of *L. coffeella* during the months of January, March and May, even though these are months of high temperatures. Among the hypotheses for the absence, or low abundance, of *L. coffeella* larvae during prolonged or torrential rains is the elimination of adults. Since this lepidopteran is small and fragile, rain and its mechanical strength may affect the viability of its populations. According to Meireles et al. (2001), plants under normal conditions (i.e., without water stress) have adequate biochemical conditions for their natural defenses to function normally and, thus, help defend against pests. Plants under water stress, however, have altered functions and are more susceptible to pests.

Monitoring infestations of *L. coffeella* by counting infested leaves along with monitoring climatic conditions can help construct integrated management strategies for this pest. Pesticide use should be based on constant and well–conducted studies, since excessive use and inappropriate application times can cause mortality to important predators that help control these insects and induce resistance. Thus, the present study helps to better understand the occurrence of peaks in abundance of *L. coffeella* and its predators and will help to implement more adequate control and management plans.

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